

Virginia Groundwater

NOT exactly underground rivers....



St. Paul Subterranean River National Park

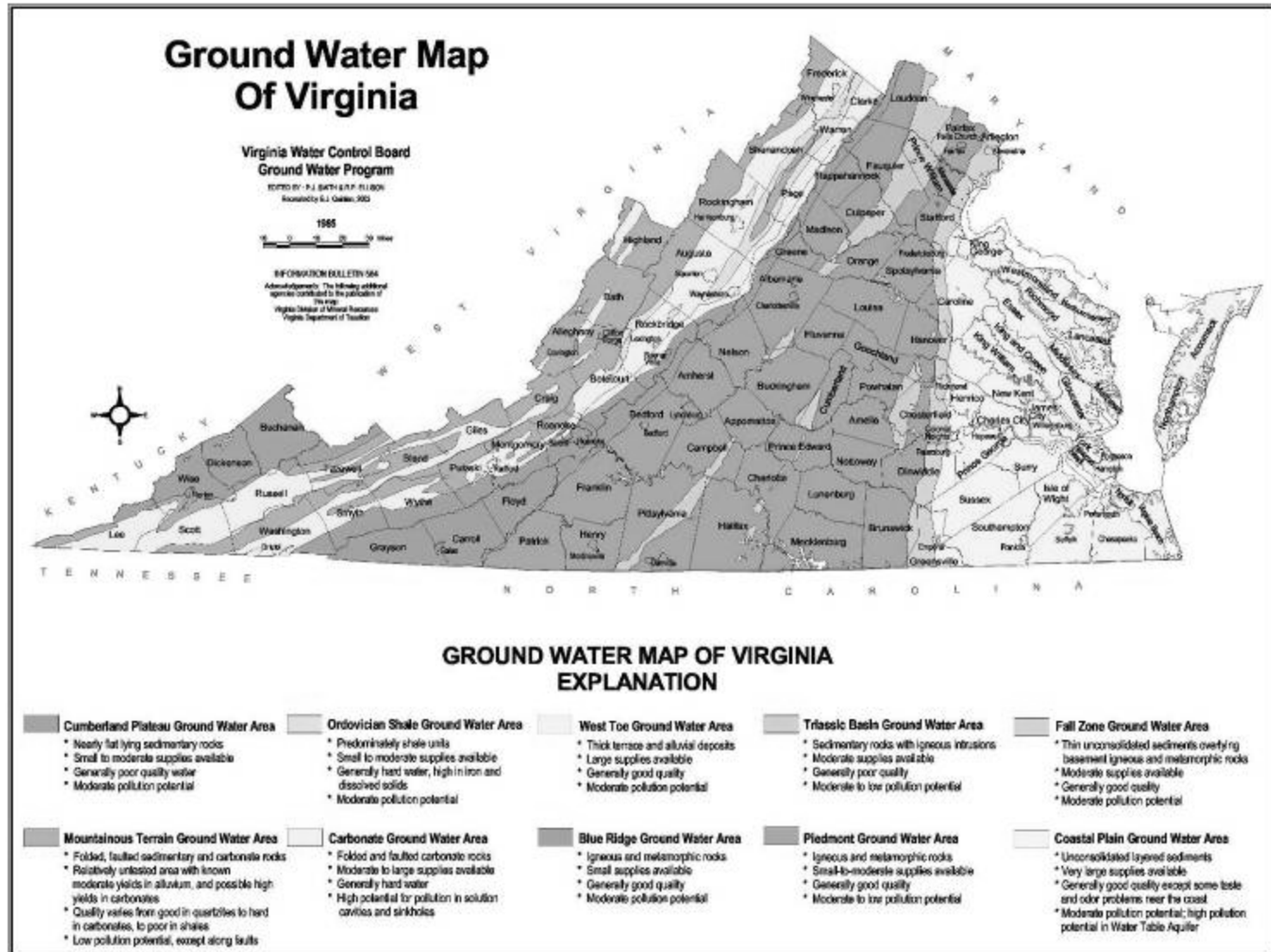
Virginia Groundwater

- **Cumberland Plateau**
- **Valley and Ridge**
- **Blue Ridge**
- **Piedmont**
- **Coastal Plain**



St. Paul Subterranean River National Park

Physiographic Provinces



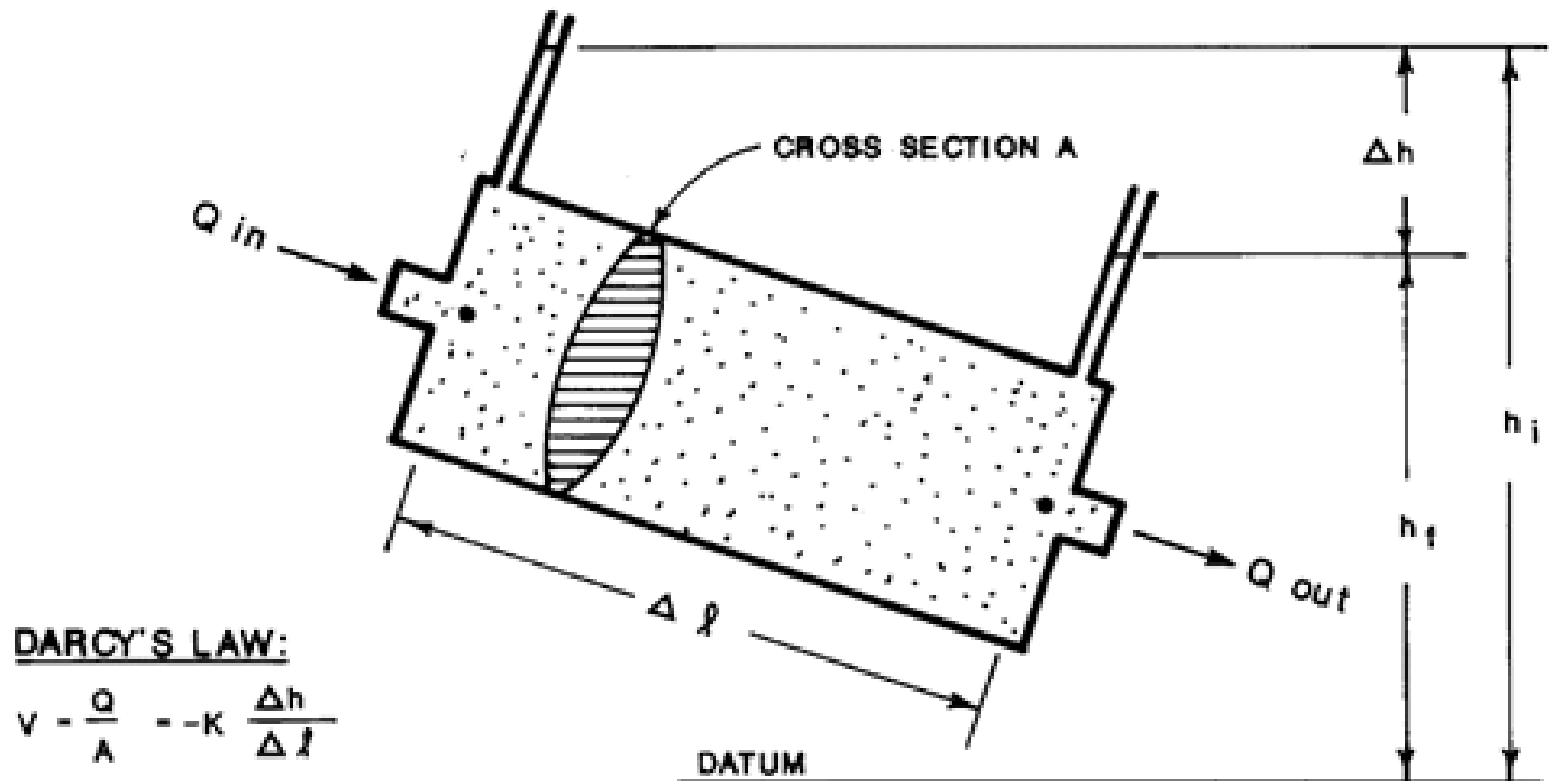
Virginia's Coastal Plain

- **Highly productive wells throughout the system**
- **Potential for salt water intrusion (SWI)**
- **Interference between users**
- **Applicability of Darcy's Law – the fundamental groundwater equation.**

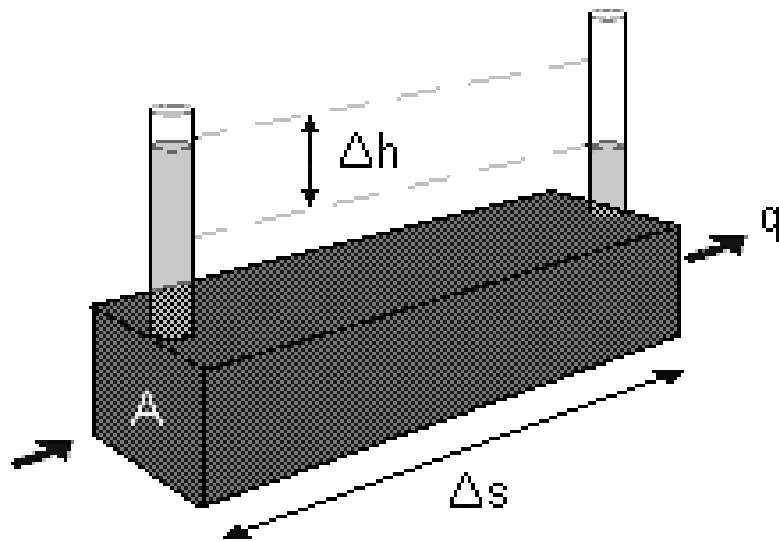


Darcy's Law

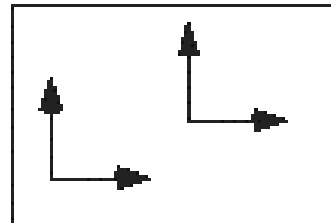
The Darcy Apparatus



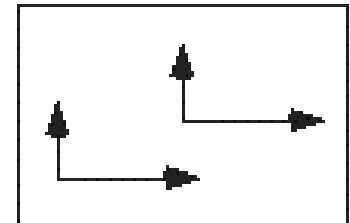
“Darcy Sandbox”



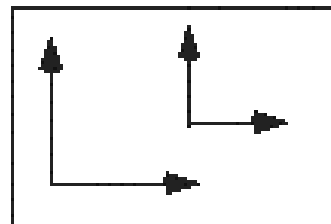
Assumes Isotropic and Homogeneous Medium



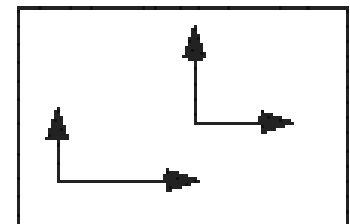
Isotropic, Homogeneous



Anisotropic, Homogeneous



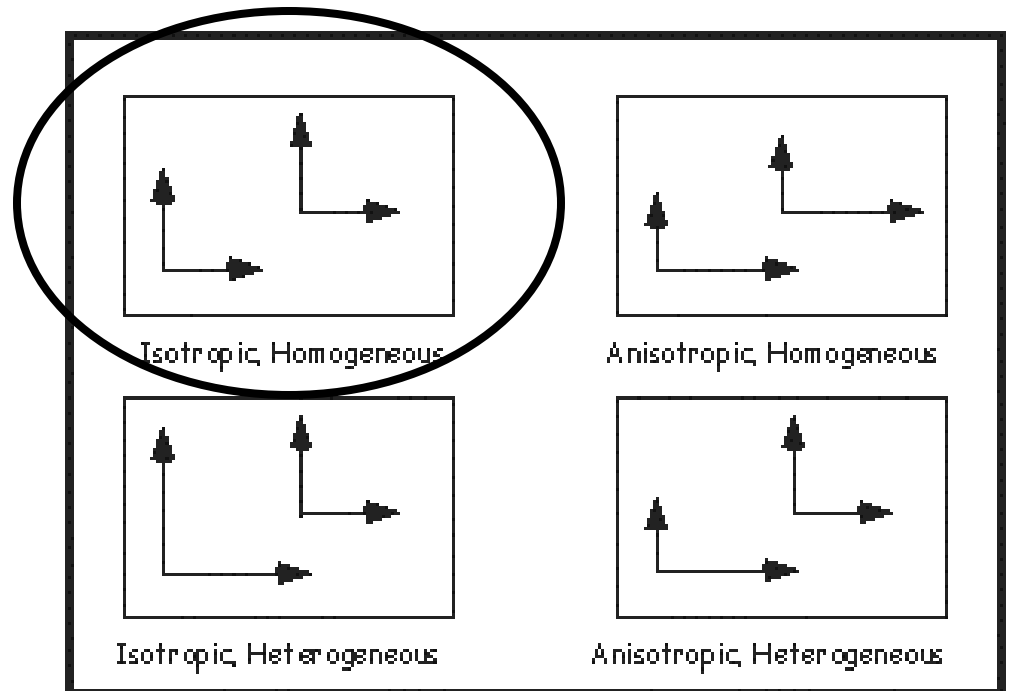
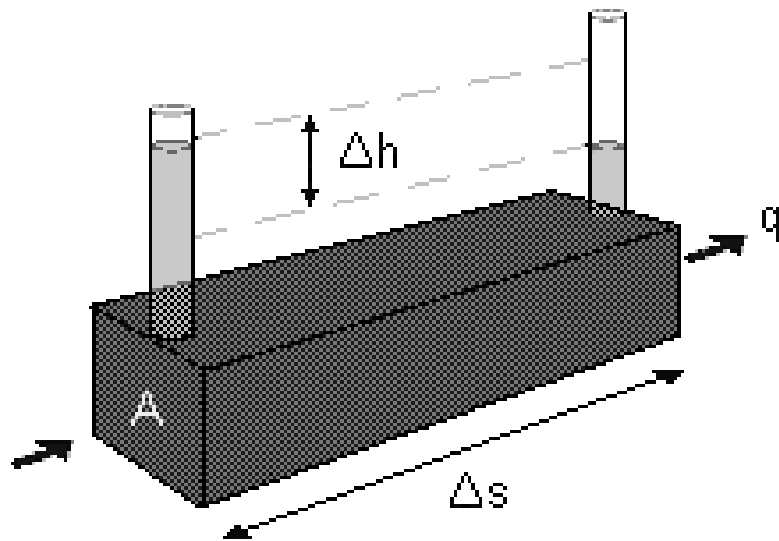
Isotropic, Heterogeneous



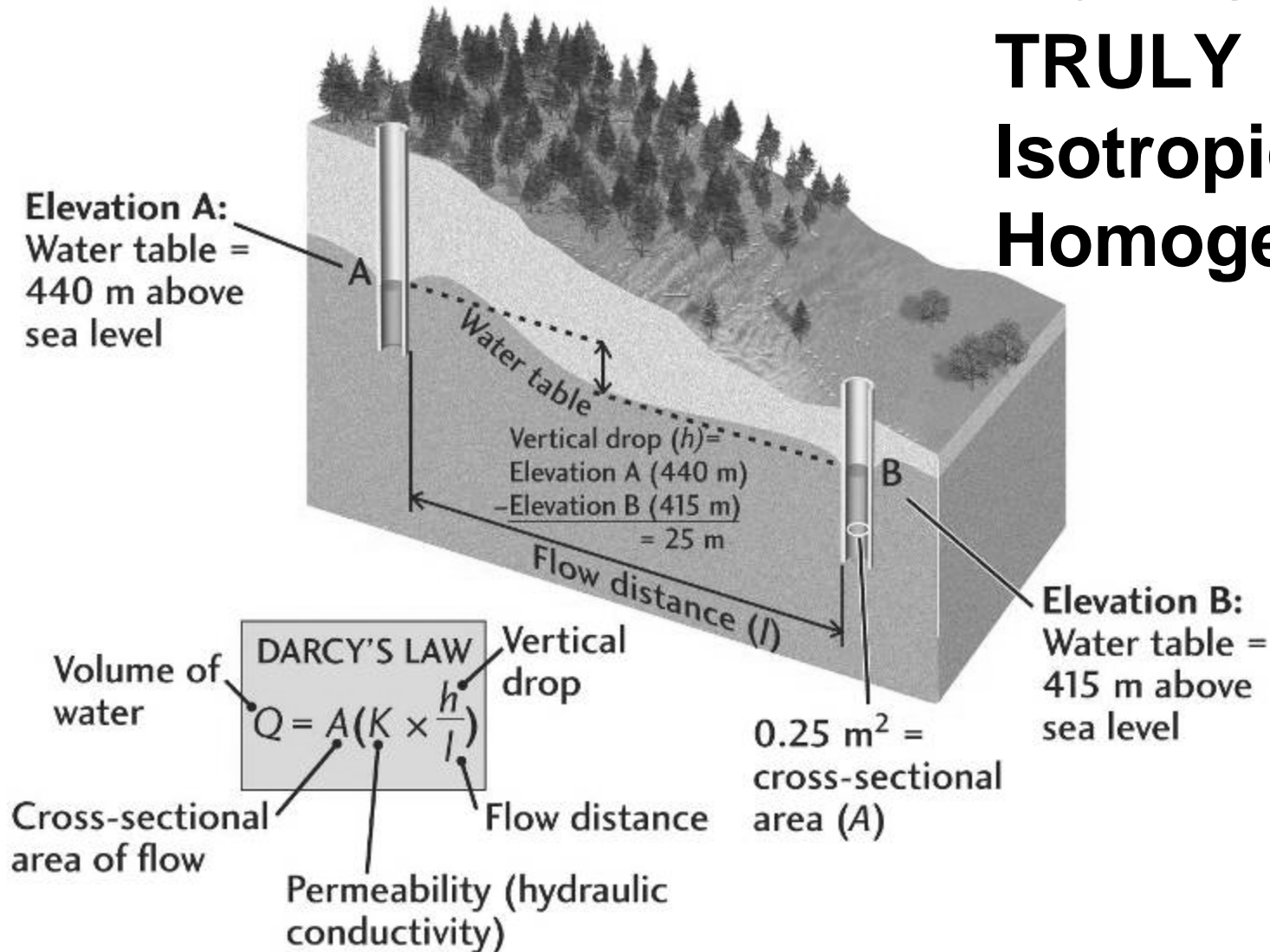
Anisotropic, Heterogeneous

“Darcy Sandbox”

Assumes Isotropic and Homogeneous Medium

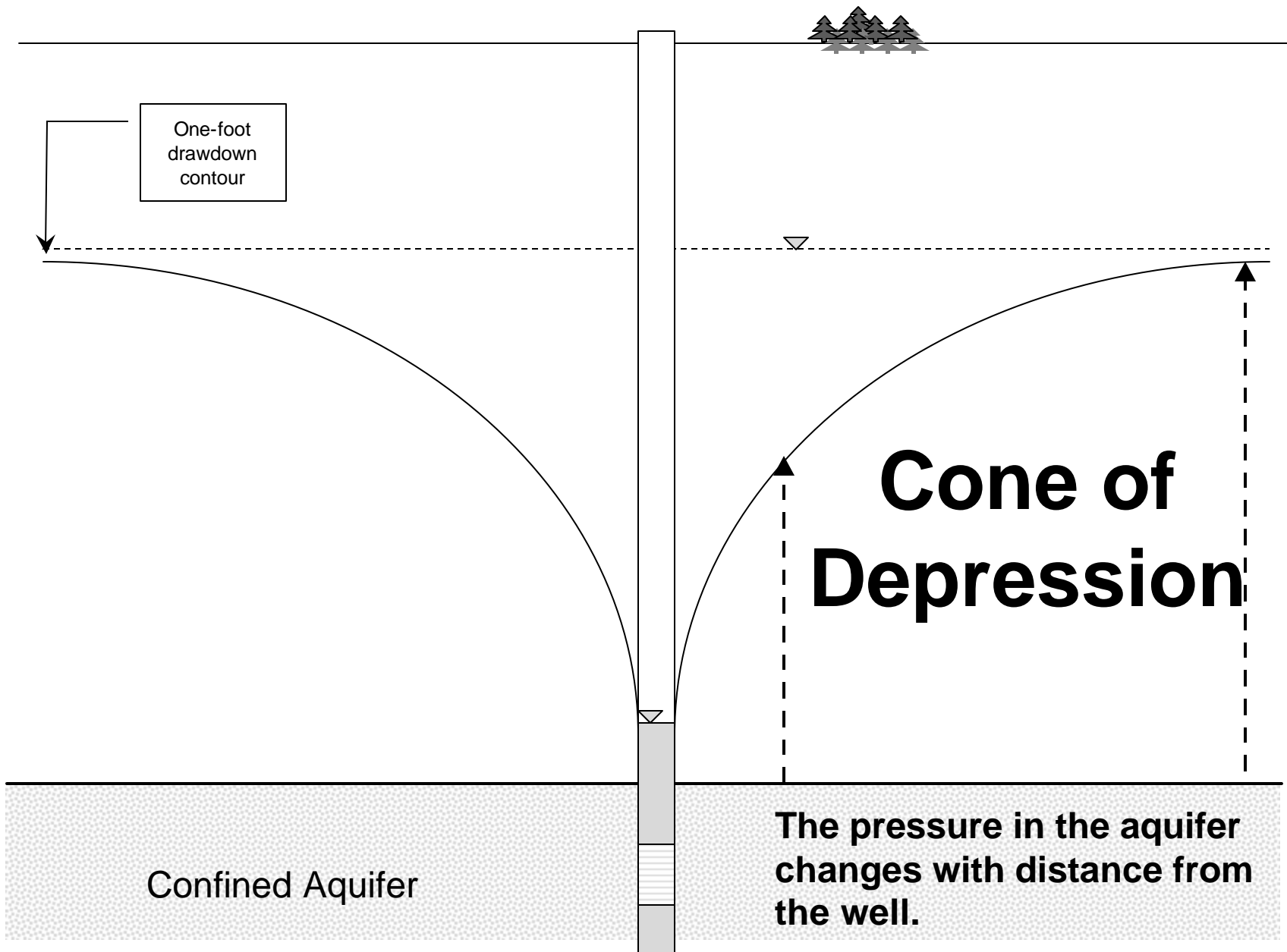


The Coastal Plain is NOT TRULY Isotropic and Homogeneous



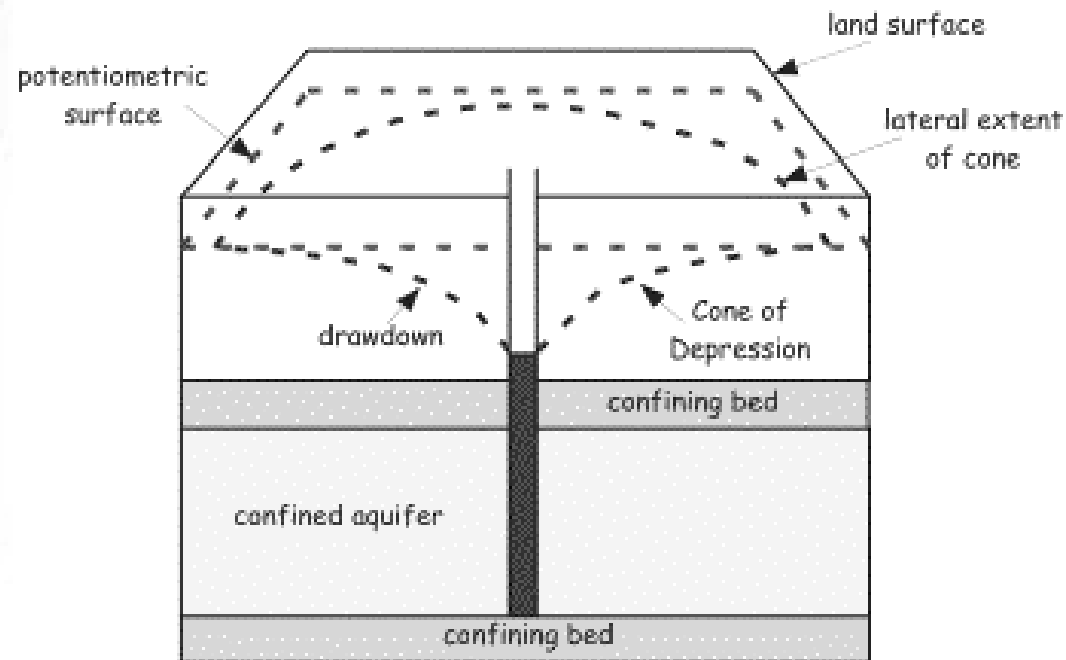
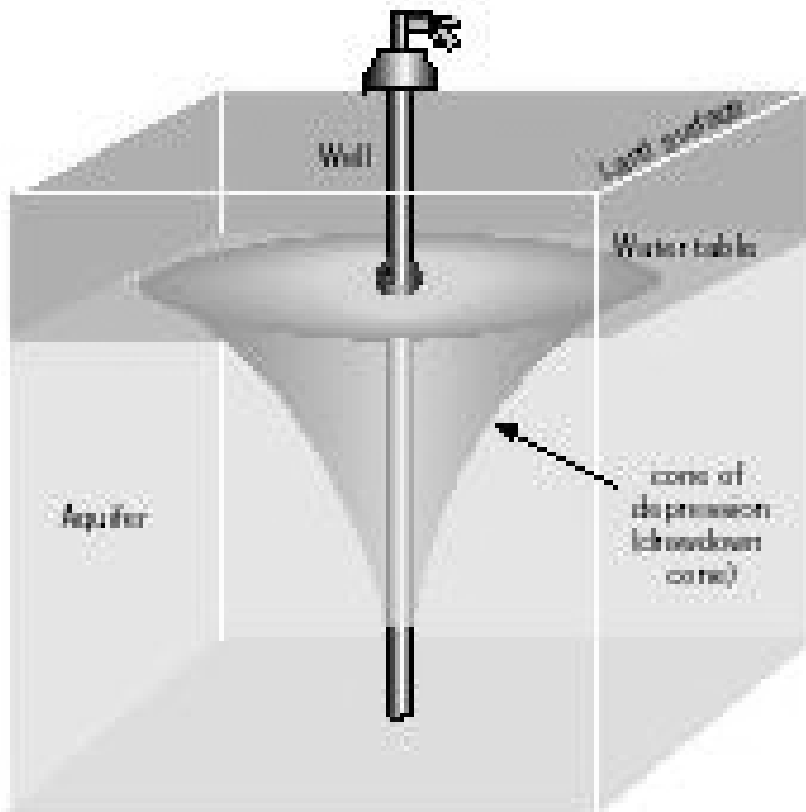
– Interference between users

- **What is a cone of depression?**
- **Regional Impacts**

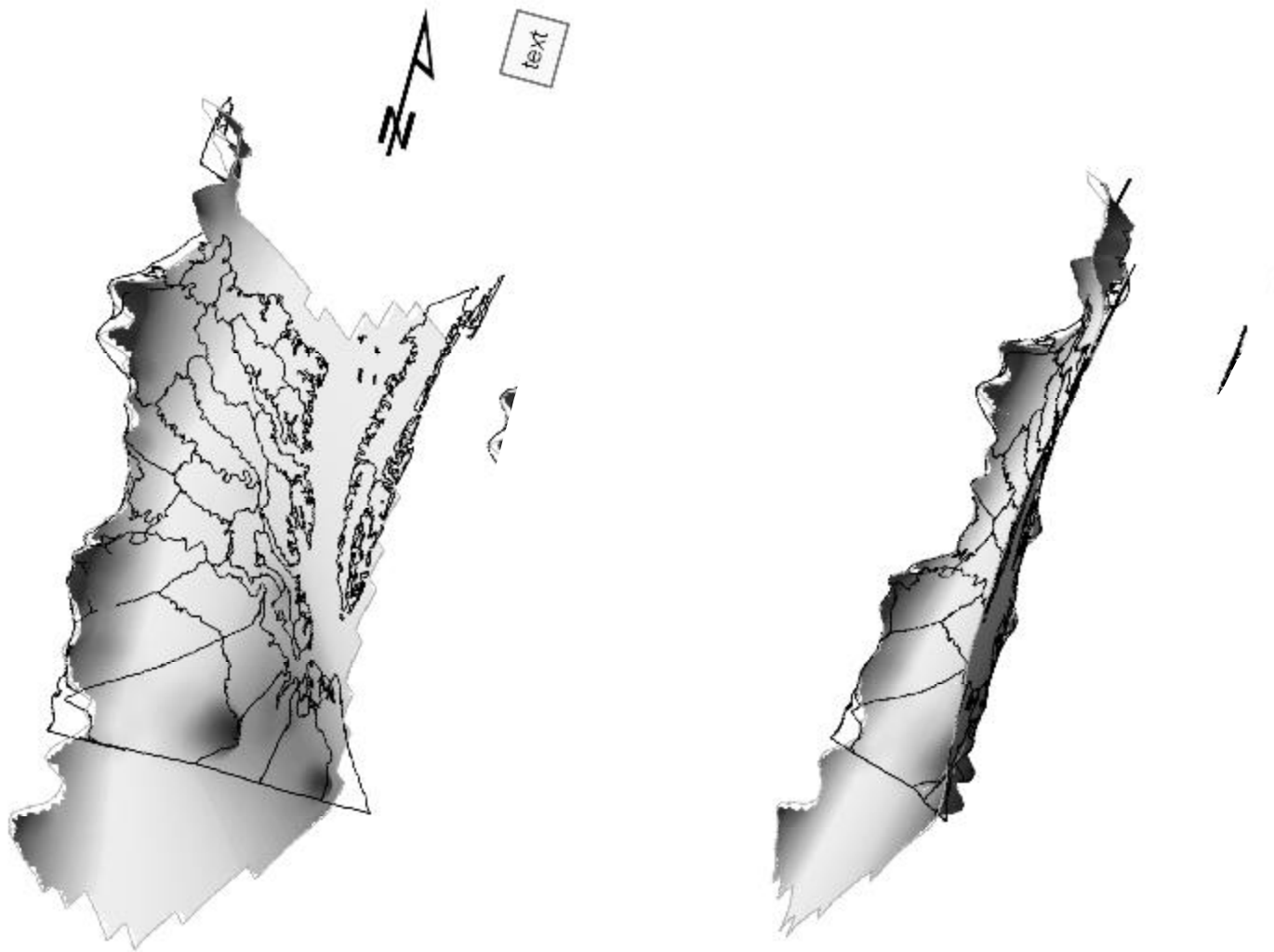


Cone of Depression

(lowered pressure in the aquifer sediments resulting from pumping a well)



modified from Heath (1993)



Regional Impacts

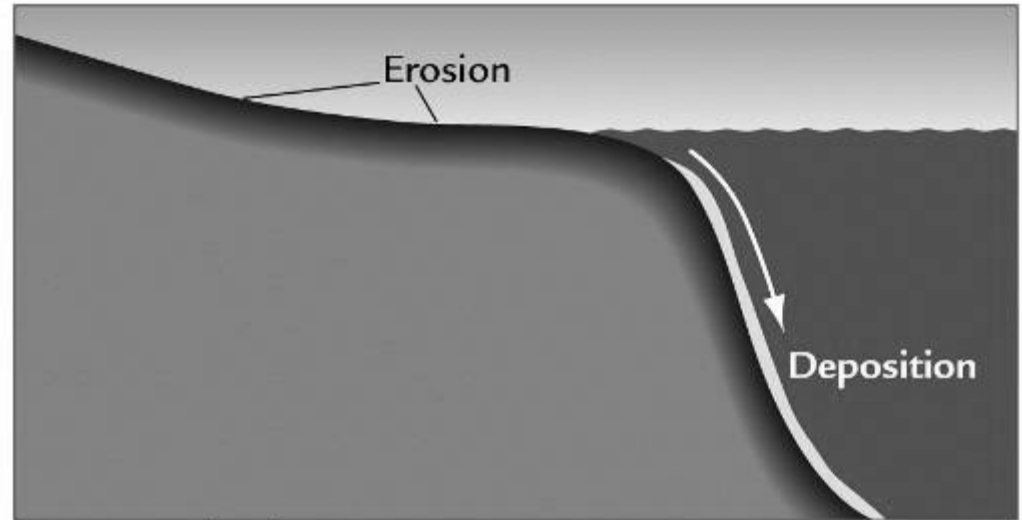
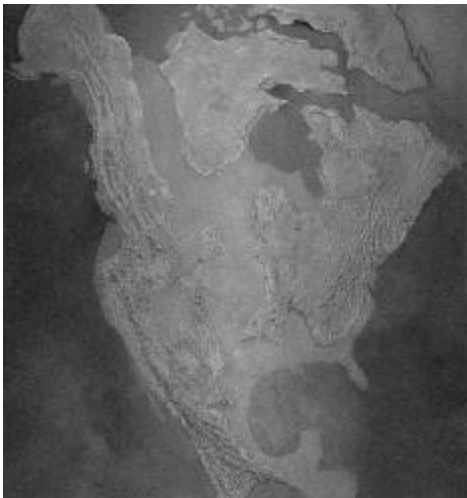
Well Interference Movie

Paul Santi, Associate Professor

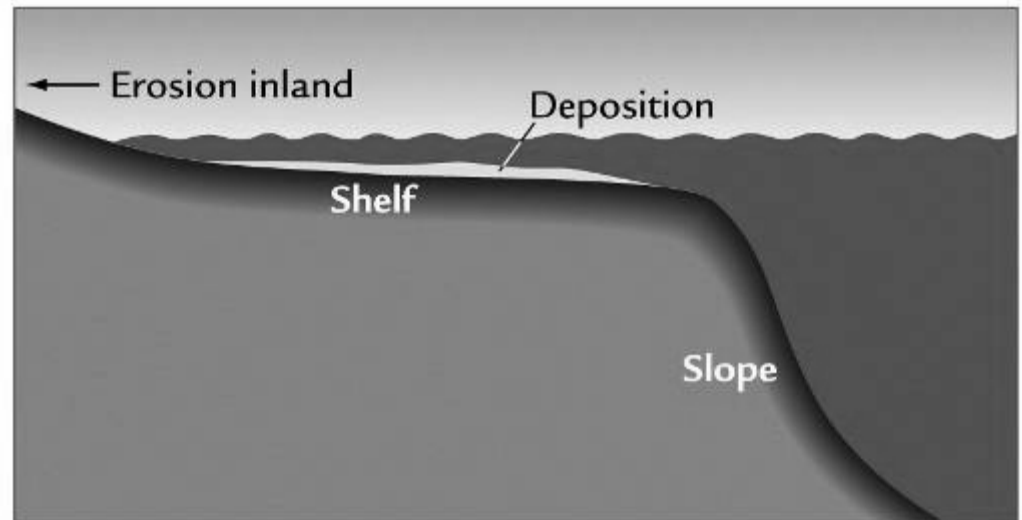
***Department of Geology and Geological
Engineering***

Colorado School of Mines

- **Depositional Environment Defines the Geology and Hydrogeology**
 - ***Marine Transgressions and Regressions***

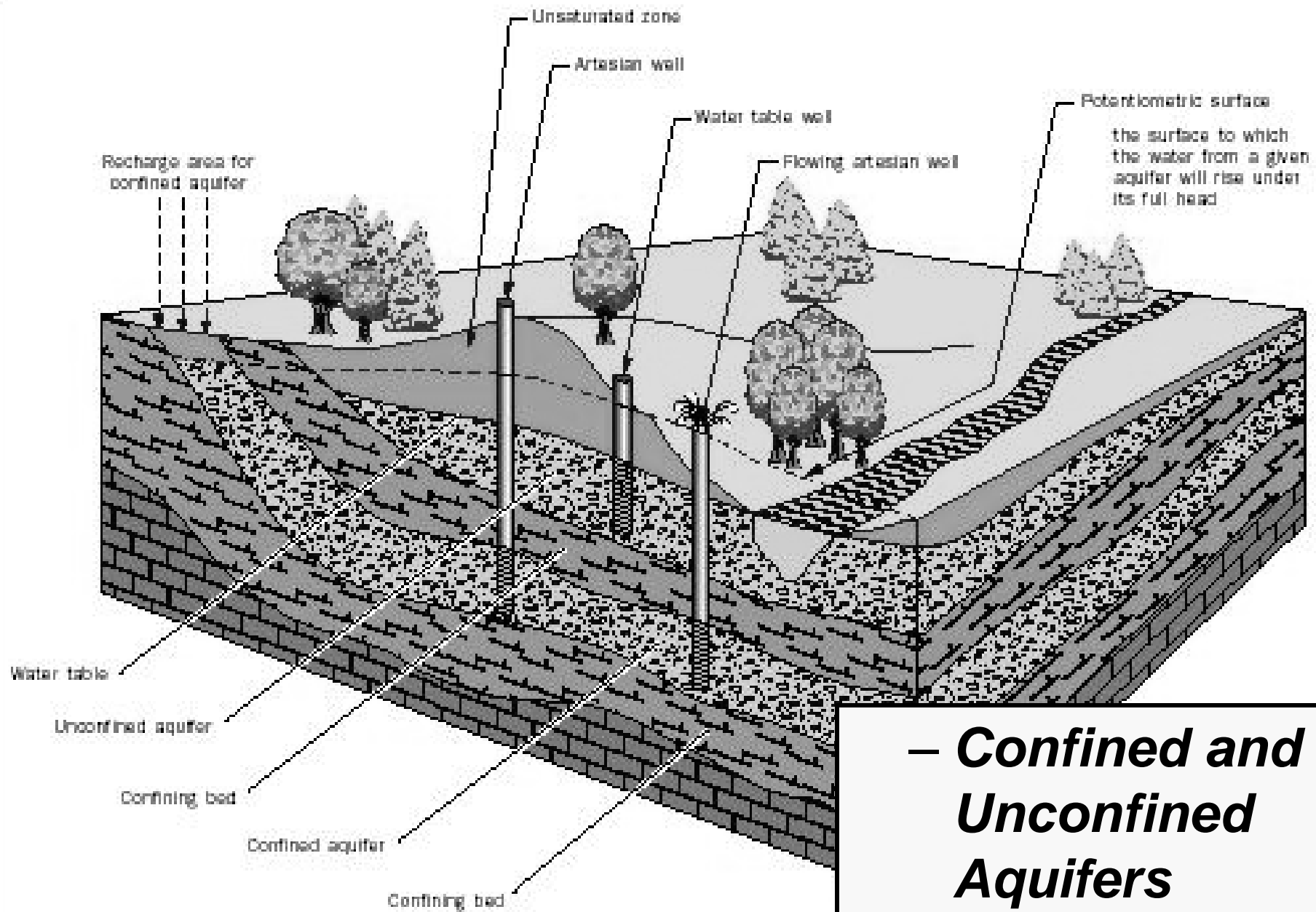


A Low sea level



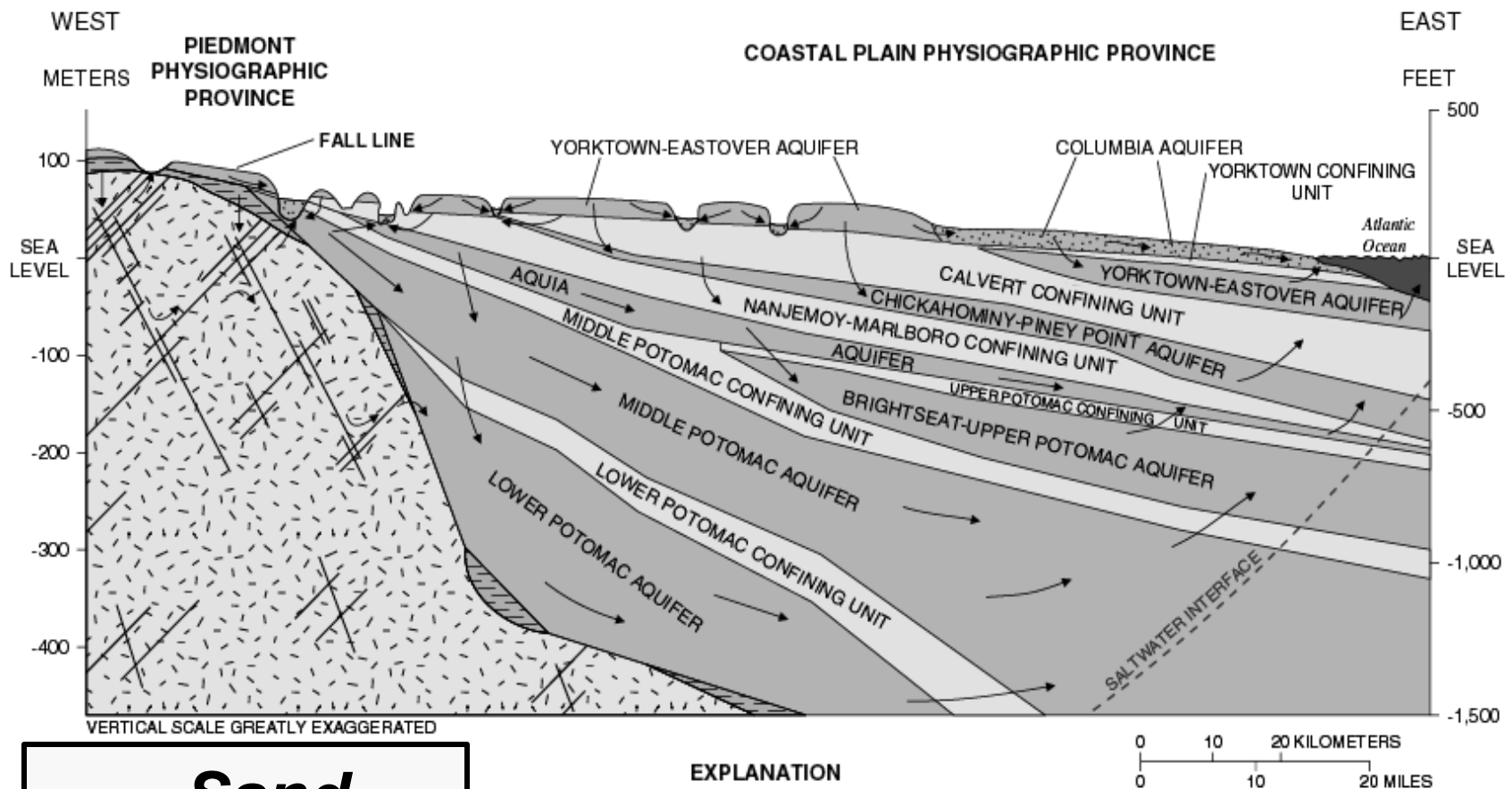
B High sea level



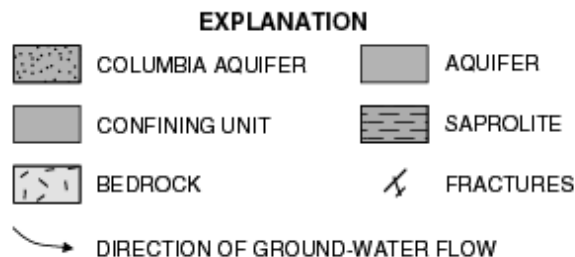


**– Confined and
Unconfined
Aquifers**

Modified from McFarland (1999)



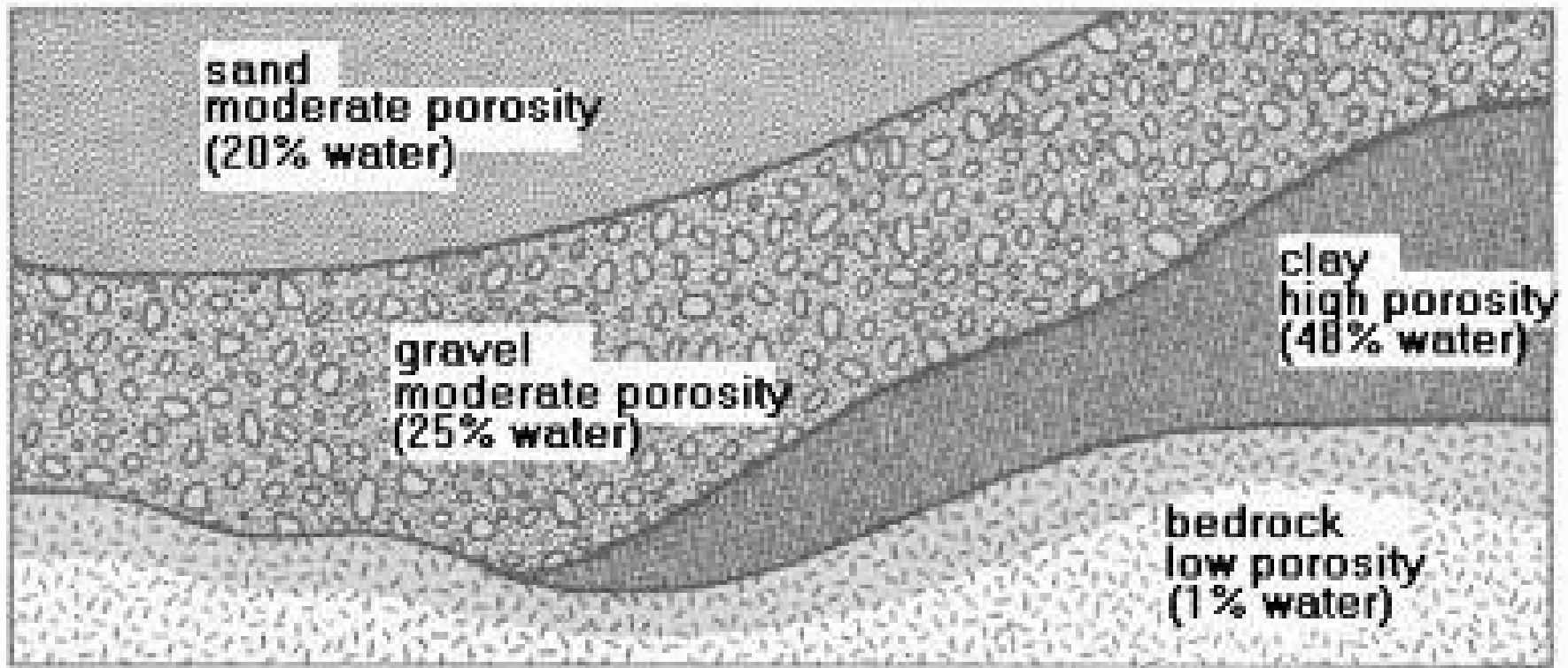
– **Sand
and
Clay
Layers**



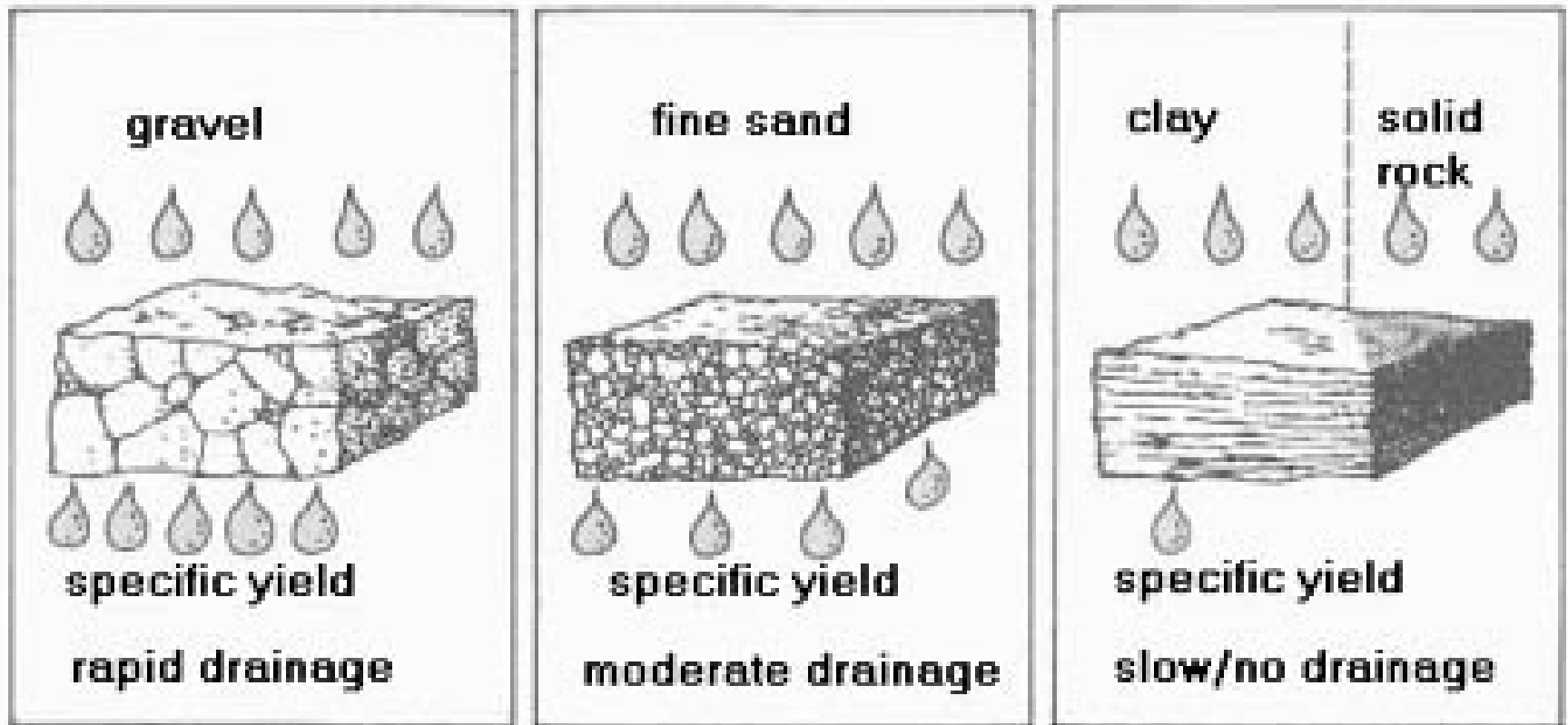
Understanding Virginia's Coastal Plain Aquifer System

- **The VA CP Aquifer System**
 - **Sands = Conductive**
 - **Clays = Storage**
 - **Confined vs Semi-confined or “Leaky Aquifers”**

The HIGH POROSITY of Clay stores most of the water in the aquifer system.



The HIGH PERMEABILITY of the sands and gravels provides transportation corridors for the water.



Specific Yield Movie

Paul Santi, Associate Professor

***Department of Geology and Geological
Engineering***

Colorado School of Mines

Understanding Virginia's Coastal Plain Aquifer System

- **Homogeneity vs Heterogeneity**
(differences between aquifers that can change with location)
 - Depositional Environment
 - Water Quality
 - Crater
- **Introduction to Well Construction**

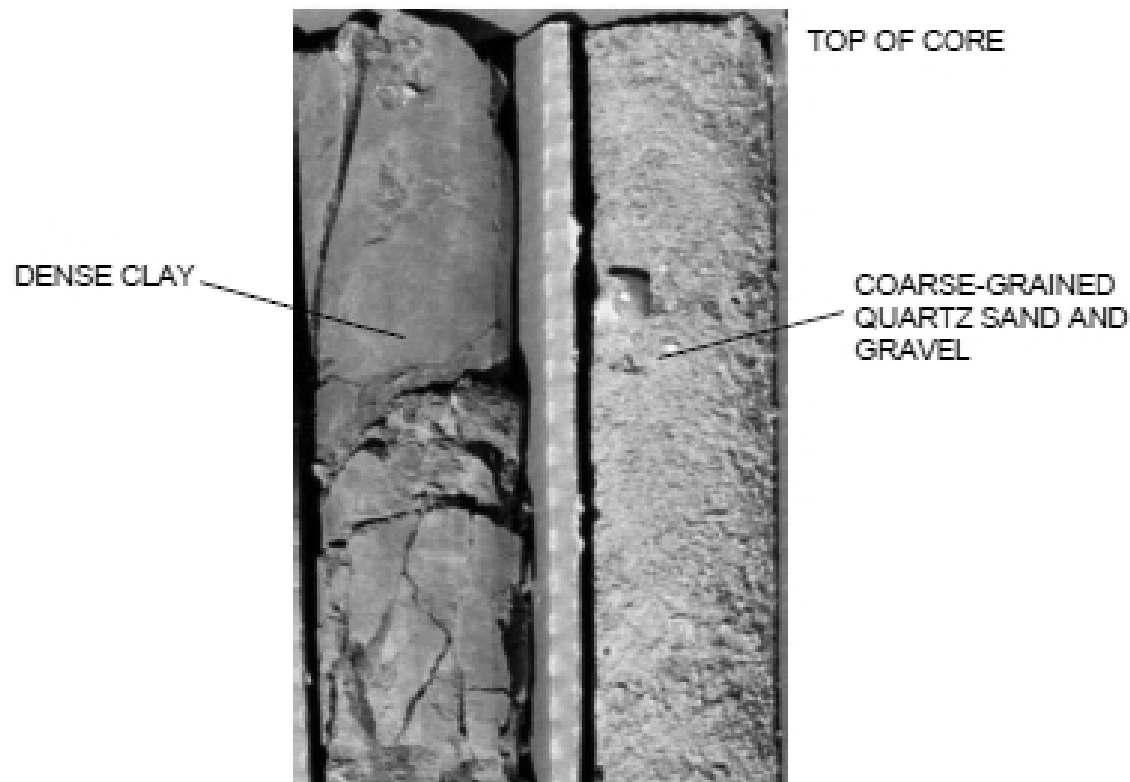
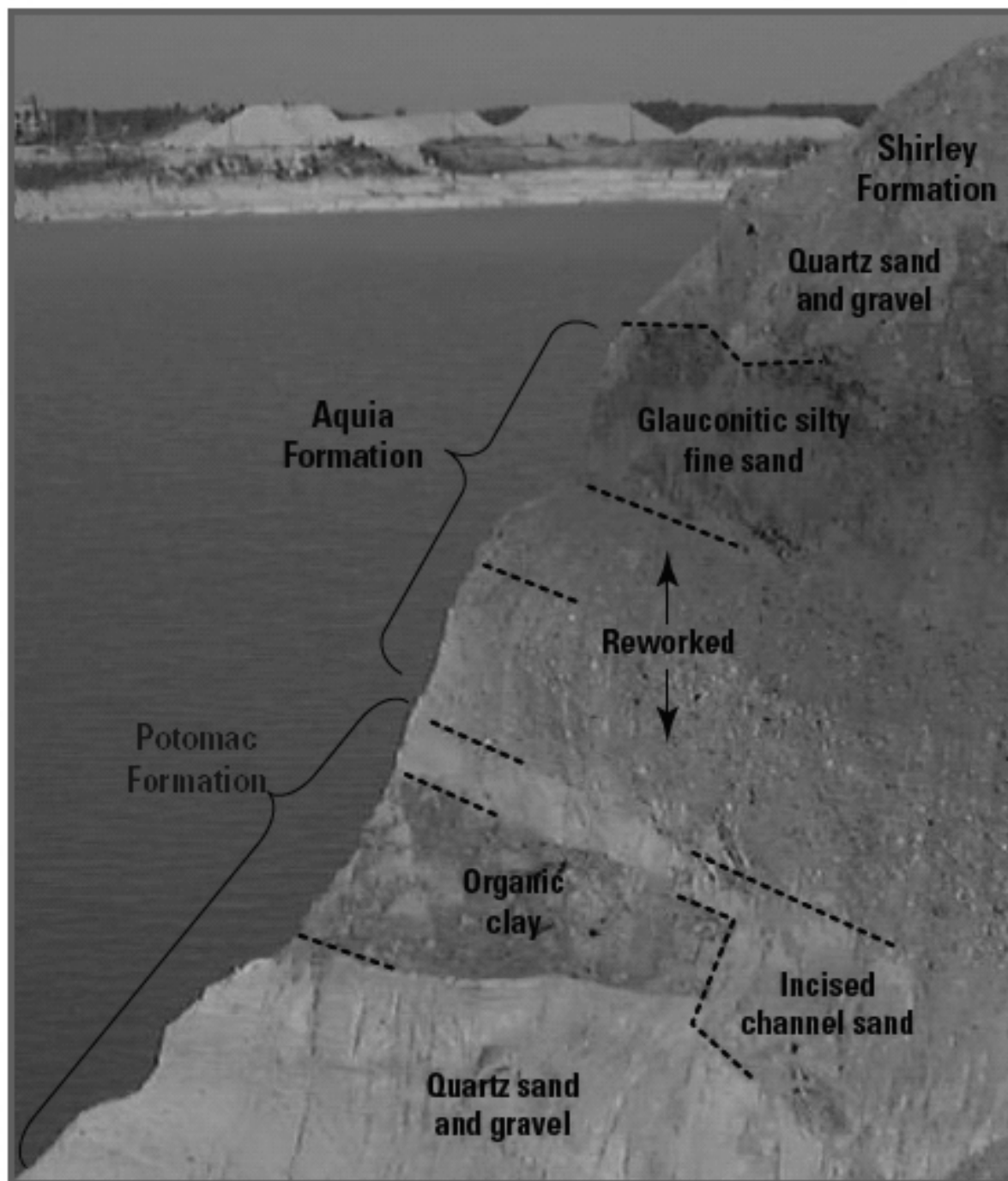
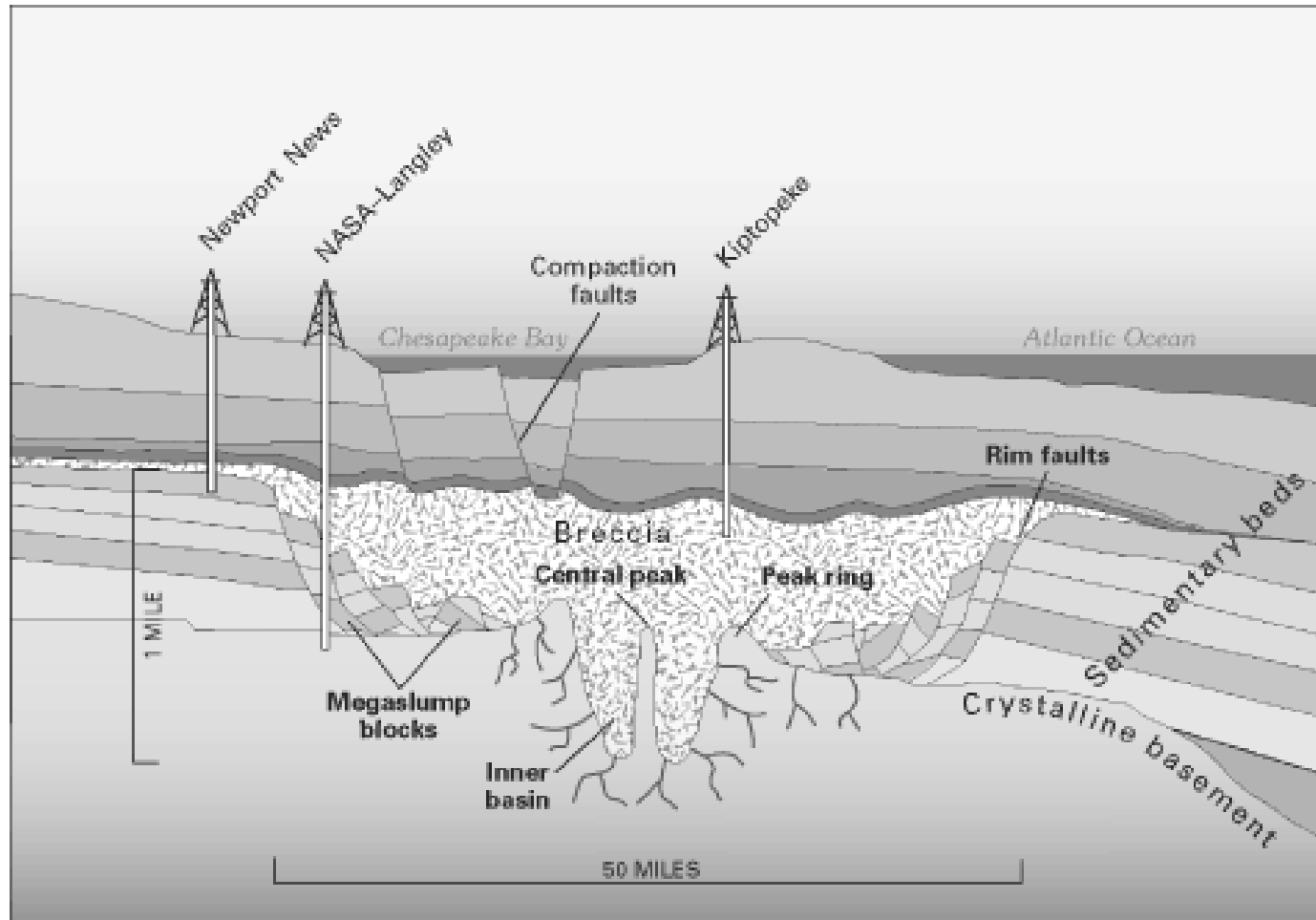


Figure 9. Fluvial-deltaic sediments of Early Cretaceous age from the Potomac Formation in the National Aeronautic and Space Administration (NASA) Langley core, borehole local number 59E 31, in Hampton, Virginia (borehole location shown on plate 1). Core diameter is approximately 2 inches, and intervals are between approximately 1,593 and 1,595 feet below land surface. Section to right consists of coarse-grained quartz sand and gravel that constitutes the Potomac aquifer. Section to left consists of dense clay that is widely interbedded within the Potomac aquifer. Blocky structure of clay reflects paleosol development, and red color results from oxidized iron. Secondarily reduced clays, colored green and other variations, also are common at other locations. Less widespread organic clays are black and commonly have a pronounced mica content that imparts a greasy consistency.

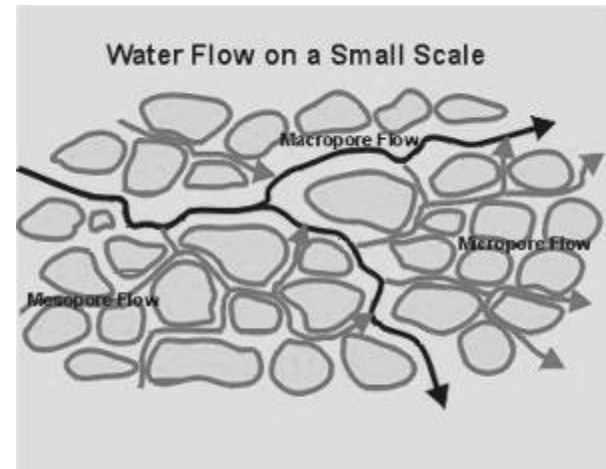
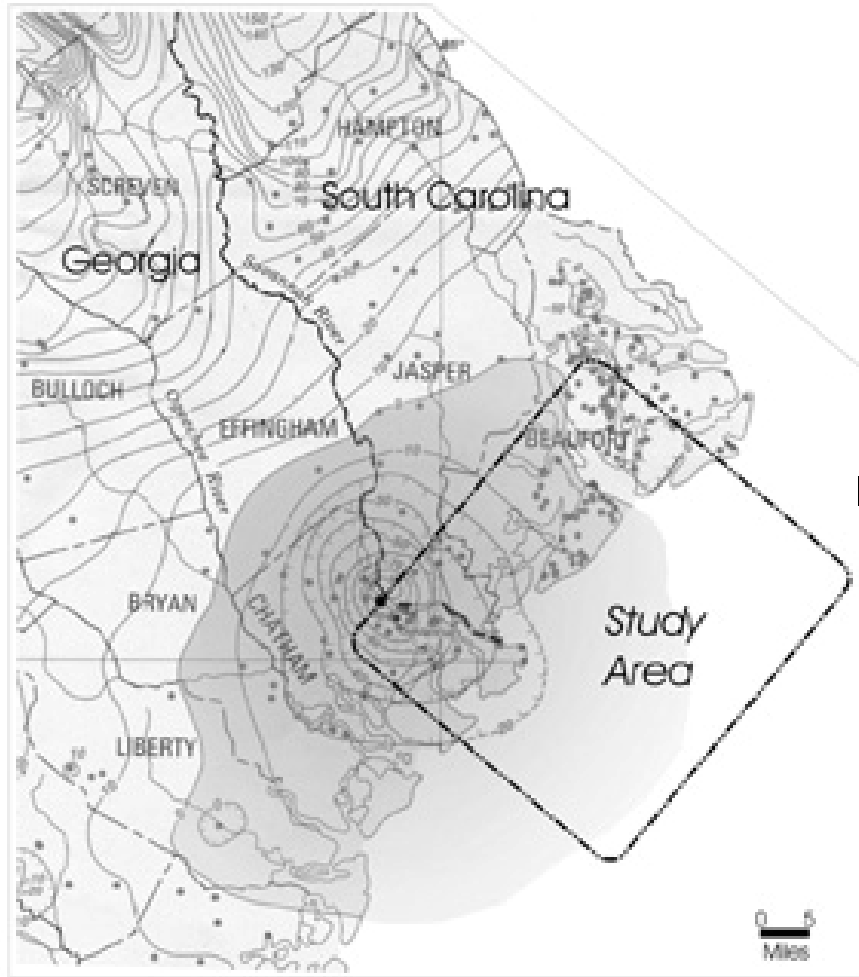


Chesapeake Bay Impact Crater



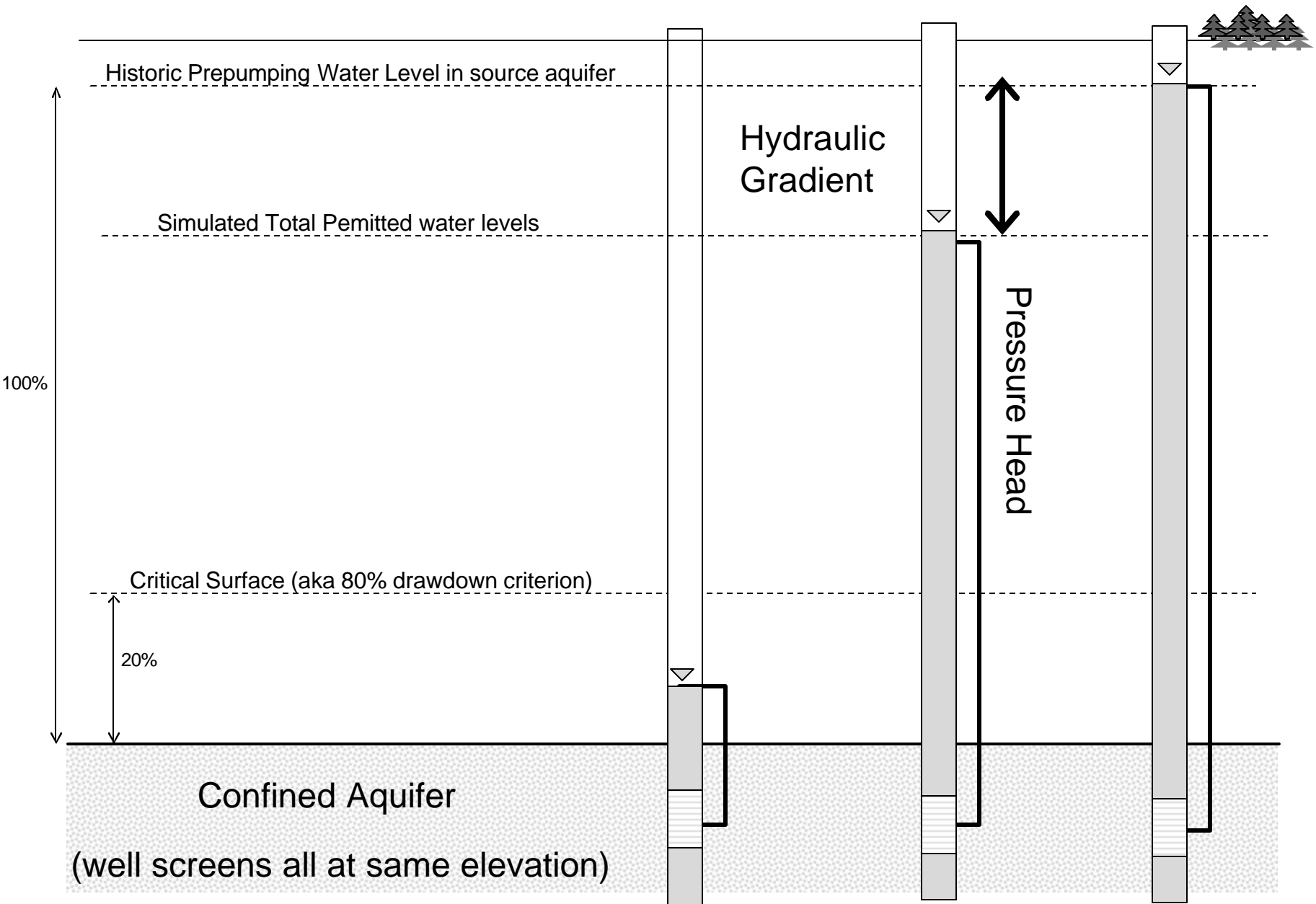
Modified from Poag (2000)

Pressure Head, Hydraulic Gradient, and the Tortuous Path



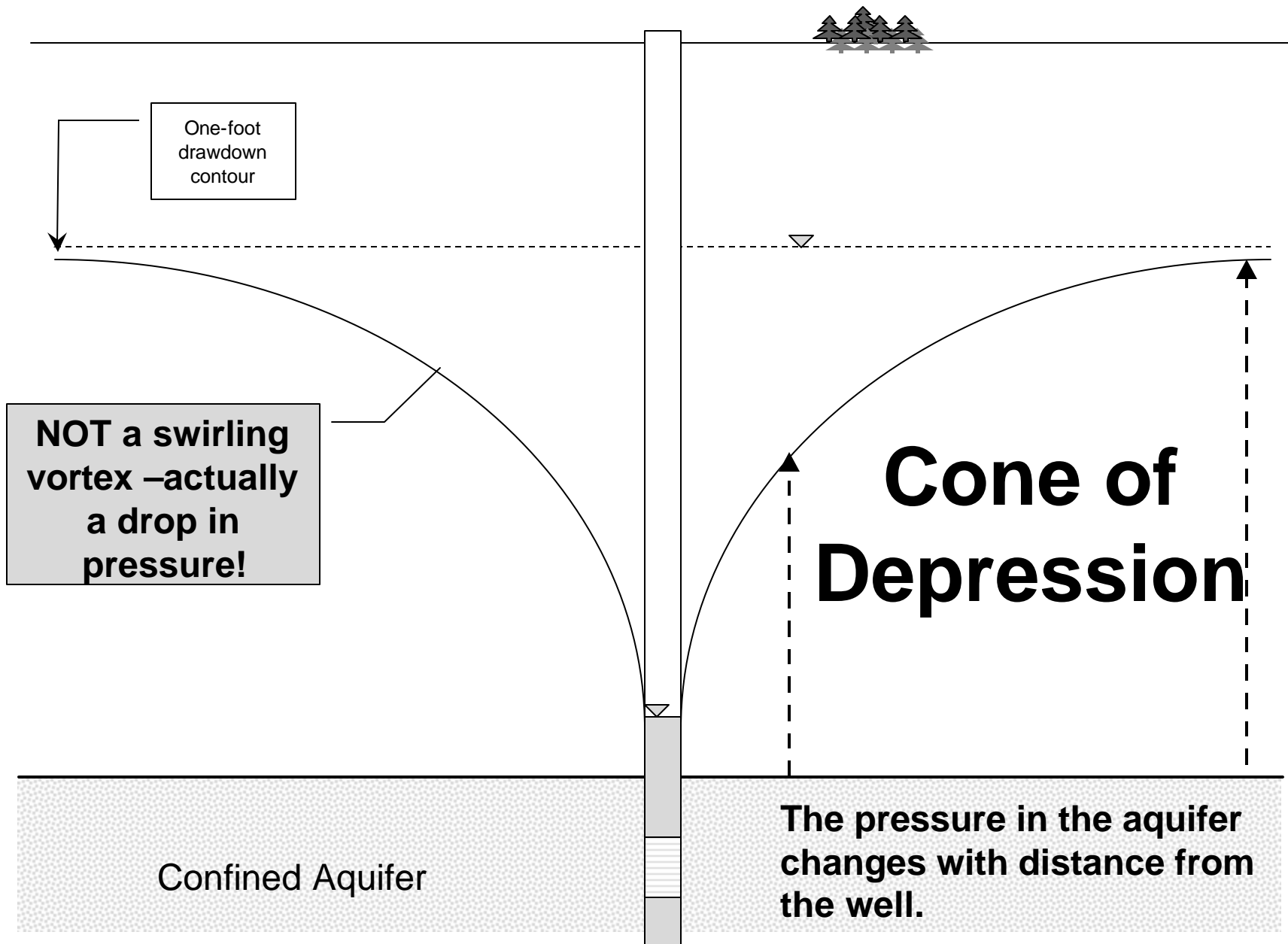
Pressure Head an important concept

**We measure water levels in wells
but we are actually measuring
pressure in aquifers.**



A municipal water supply system loses pressure when a main breaks.

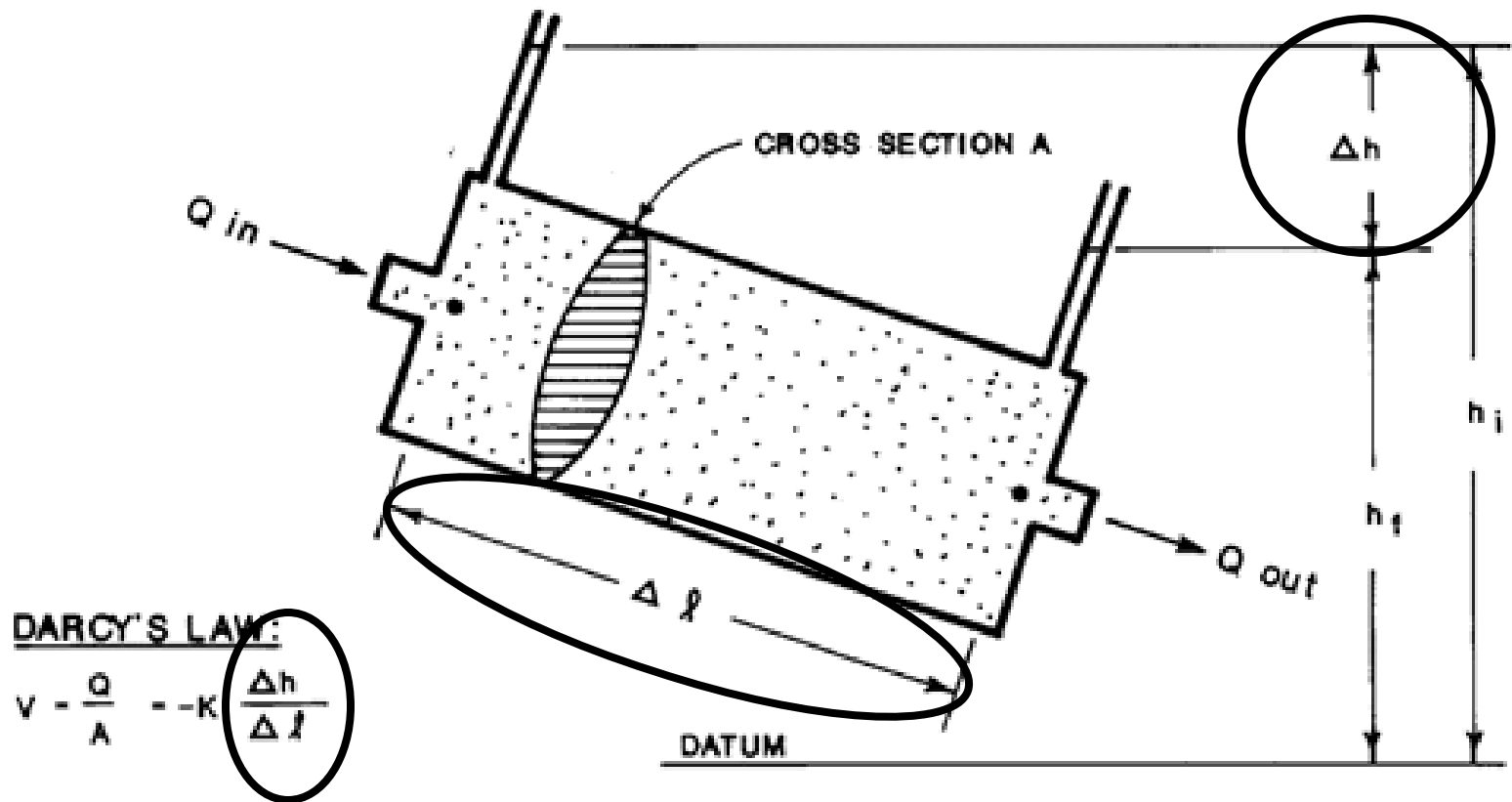




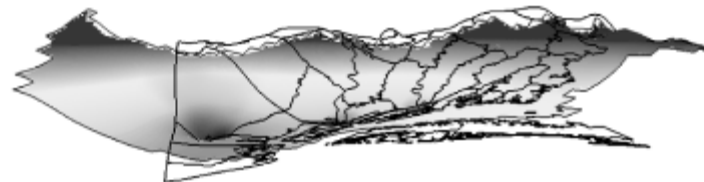
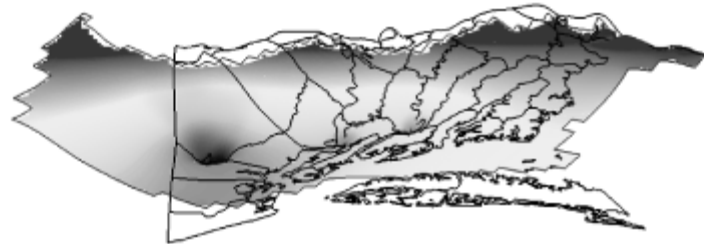
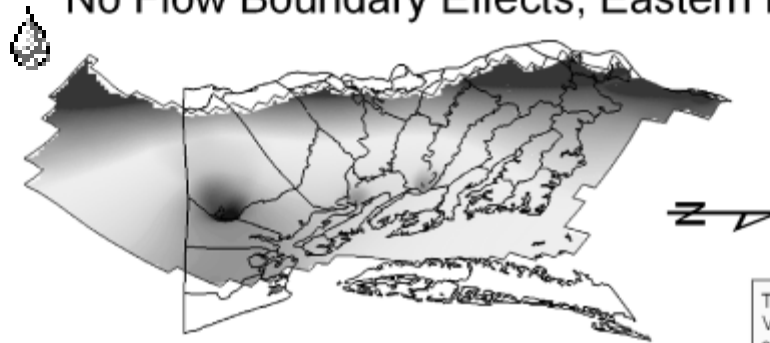
The Hydraulic Gradient (the difference in hydraulic head between two points) is the engine that drives flow within aquifers and through leaky confining zones.

Remember Darcy's Law?

It includes hydraulic gradient...



2003 Total Permitted Use: Lower Potomac Aquifer
No Flow Boundary Effects, Eastern Boundary.



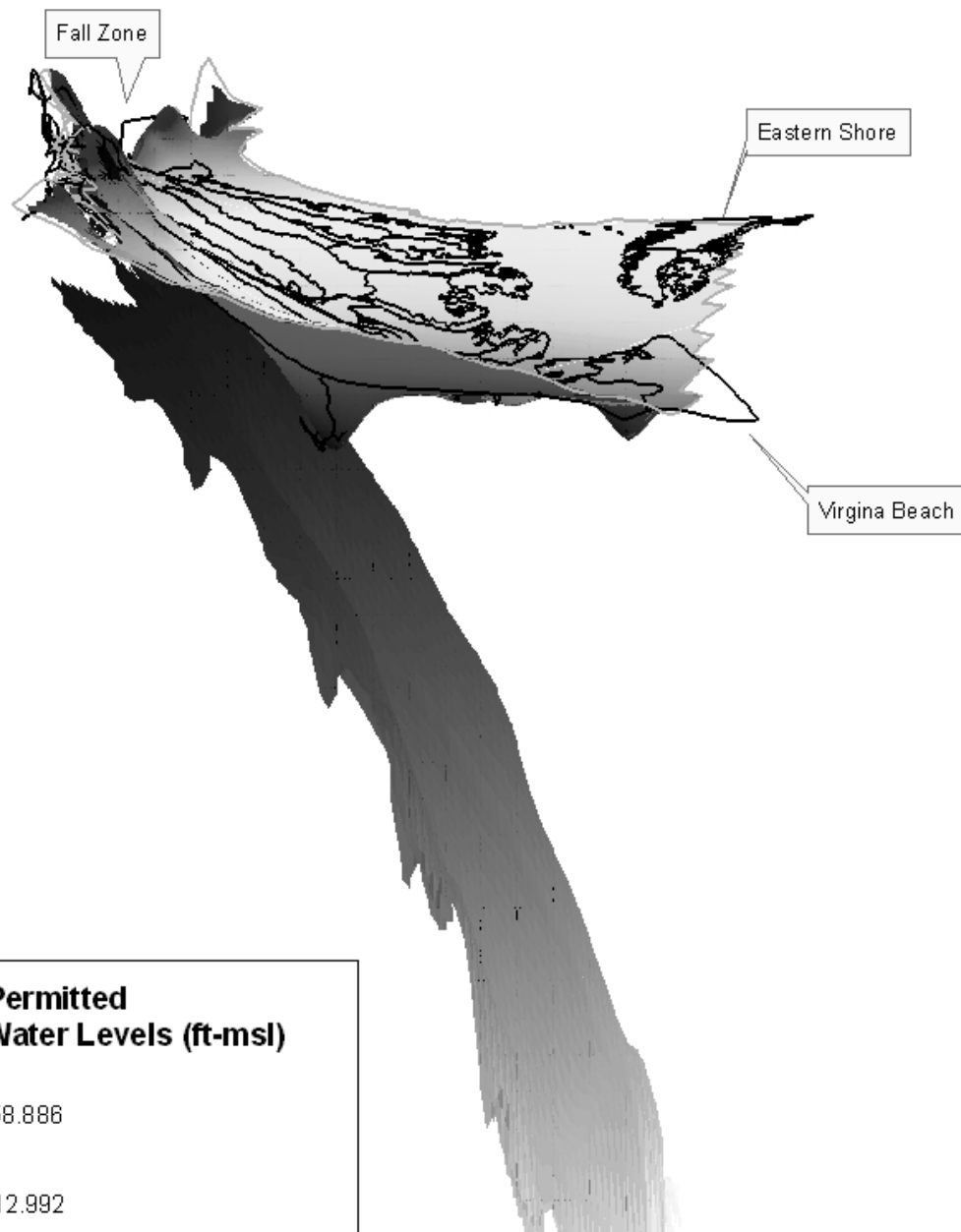
The Eastern Boundary of the Virginia Coastal Plain Model is simulated as a no flow boundary instead of as a salt-water/fresh water interface. The effects of this no flow boundary on the model output are profound. Drawdown is exaggerated westward of this boundary condition, propagating much further westward and with a greater vertical extent than if this boundary were modeled as an interface.

The S shaped curve revealed in the bottom image is telling of both the no flow boundary effects and the then unknown Chesapeake Bay Impact Crater. The no flow boundary creates a dip in Southeast Virginia. This dip is mirrored by a hump in the Bay. While the Crater itself might not have been known when this model was created, the Crater's influence on ground water was certainly observed.

Vertical Exaggeration 200%

**The
Potentiometric
Surface
illustrates the
Hydraulic Head
over an area.**

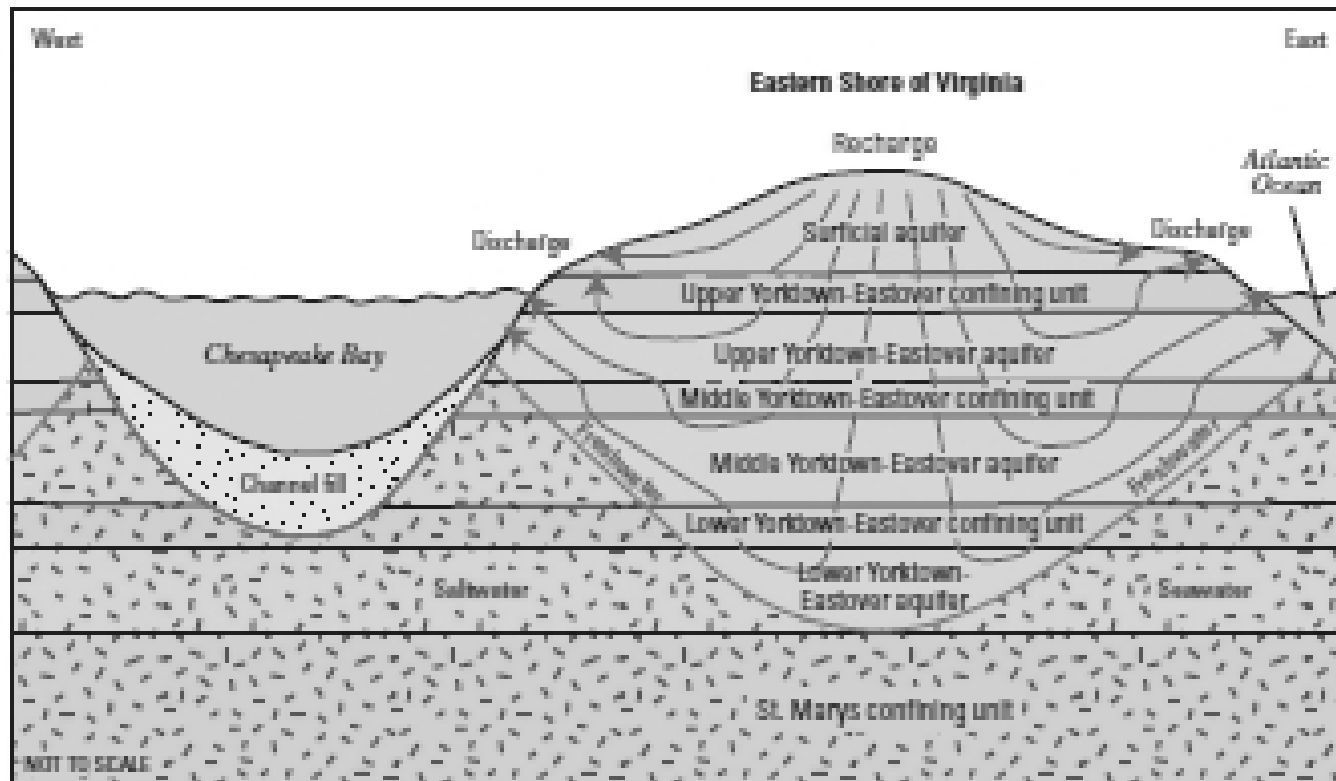
Middle Potomac Aquifer



- **Pre-development Equilibrium**
 - **Salt Water Interface**
 - **Submarine Discharge**
 - **Head Mirrors Terrain**
 - **Recharge**

Pre-development Equilibrium – Eastern Shore

The fresh water bath sits in a salt water bathtub.



EXPLANATION

→ General direction of groundwater flow

Figure 14. Schematic diagram of groundwater flow of the Eastern Shore of Virginia.

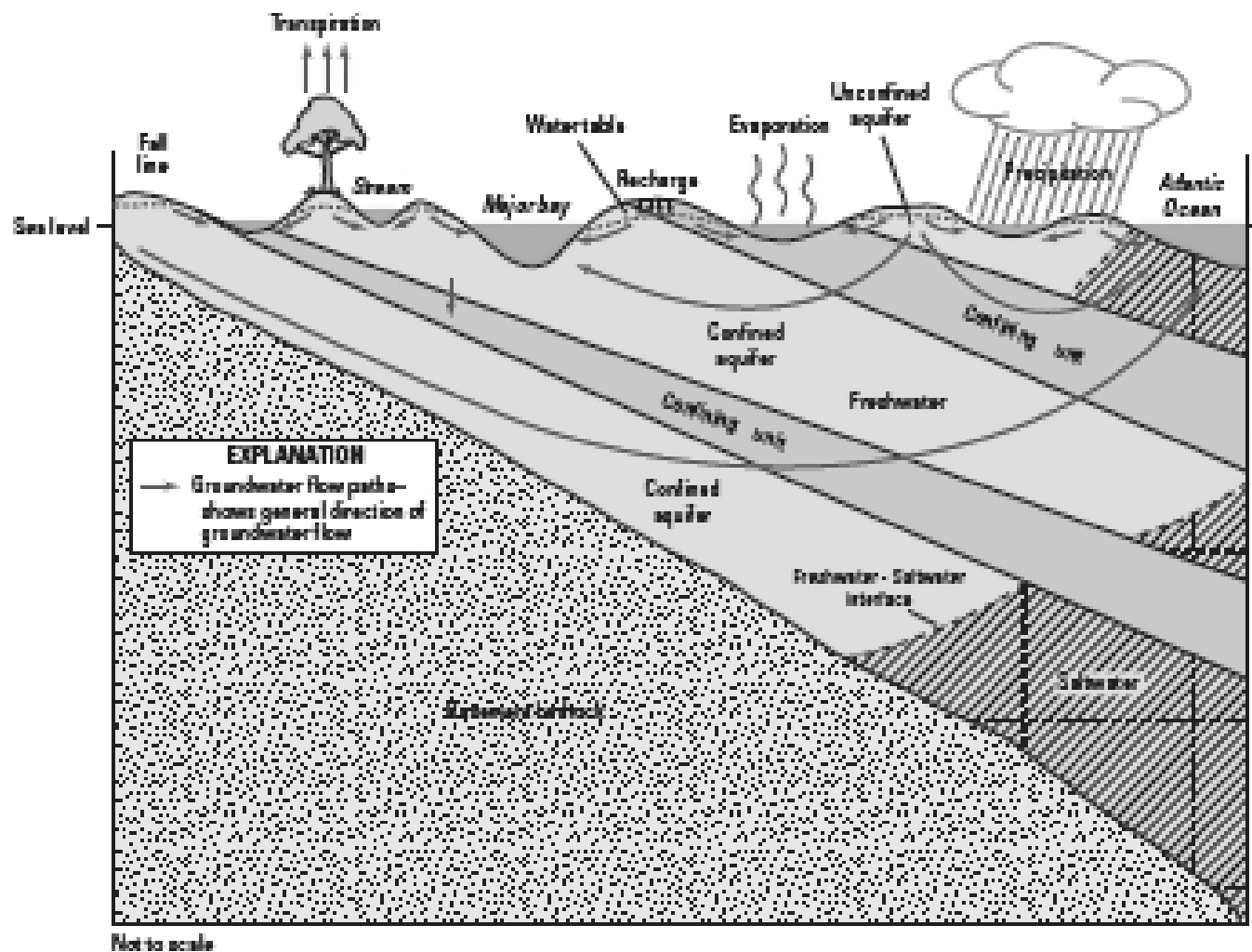


Figure 6. Generalized predevelopment groundwater flow patterns in the Coastal Plain aquifer system (modified from Leshy and Martin, 1993).

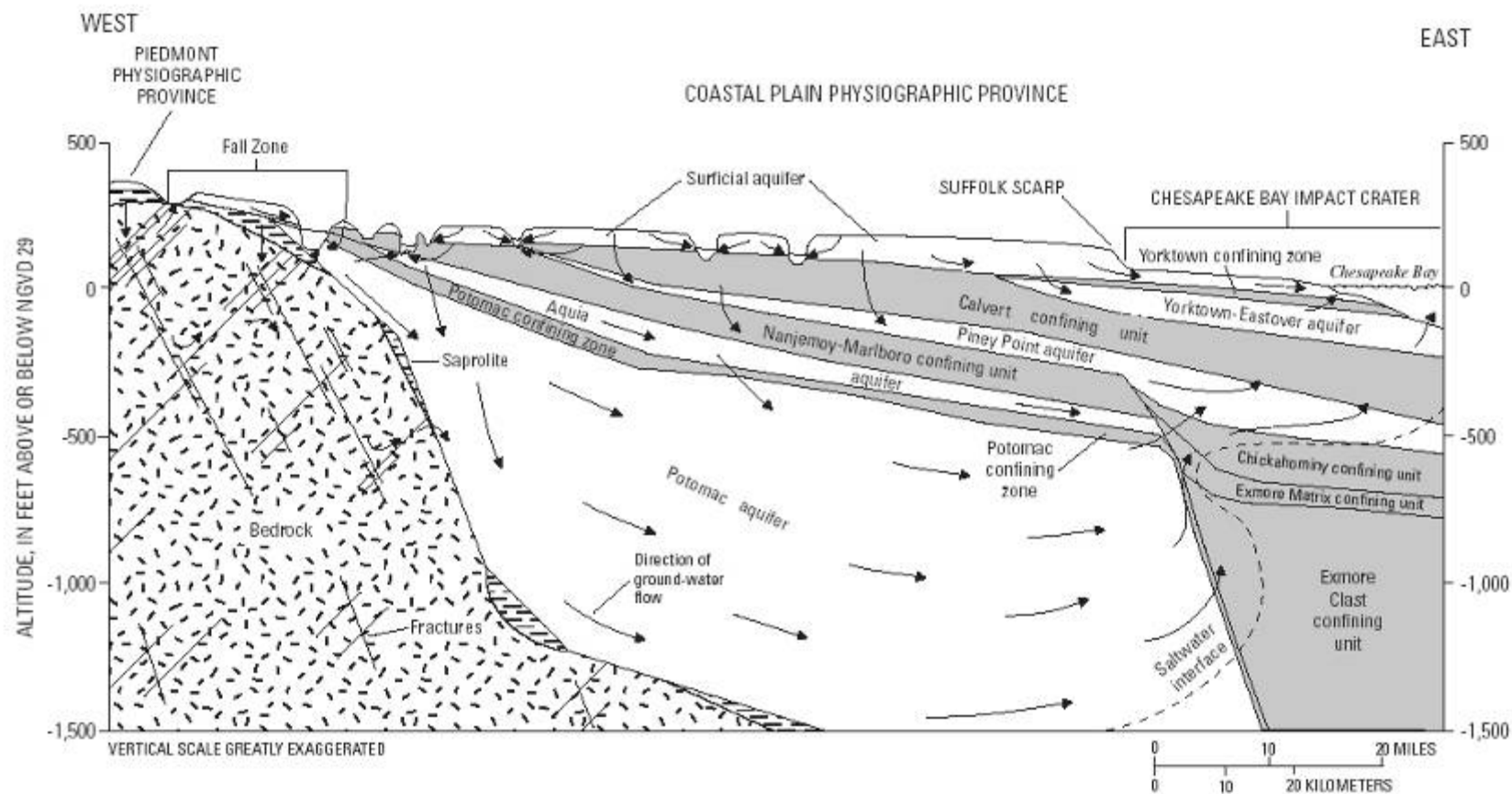
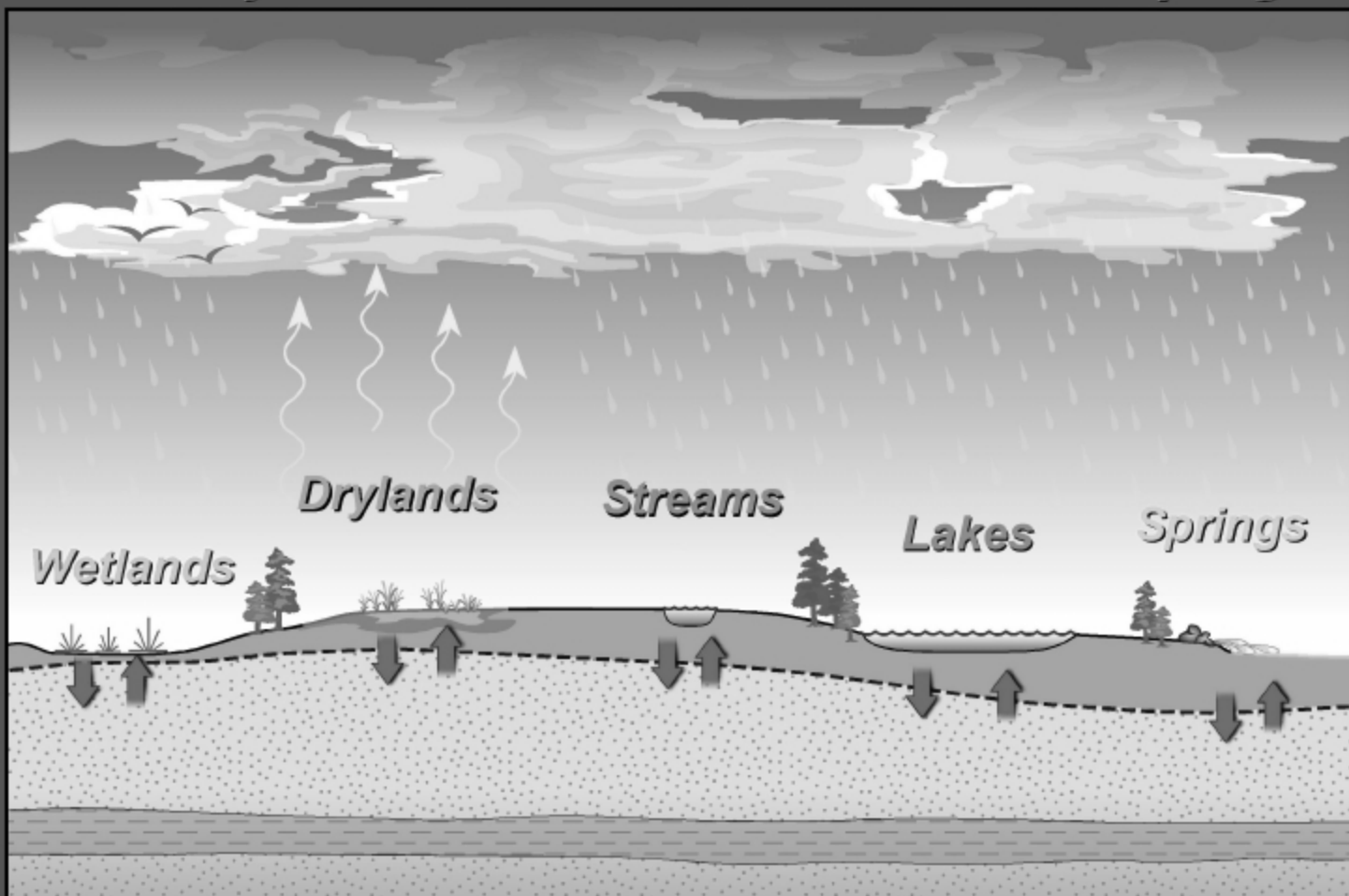


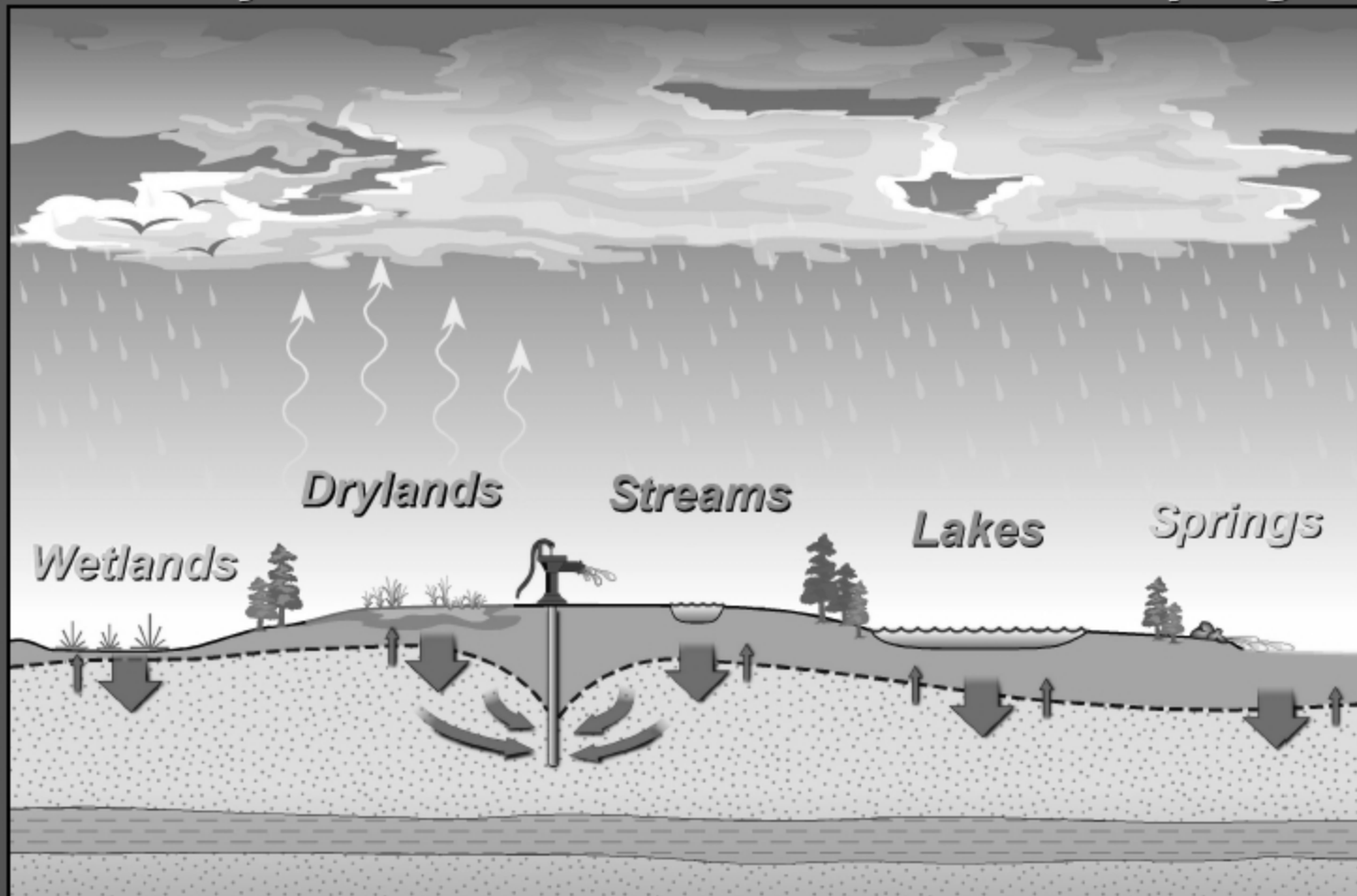
Figure 2. Generalized hydrogeologic section and directions of ground-water flow in the Virginia Coastal Plain (altitude relative to National Geodetic Vertical Datum of 1929).

Steady-State Water Balance— no Pumping



- **Post-development Equilibrium**
 - **Increased flow gradients**
 - **Potential for salt water intrusion including upconing**
 - **Change in well capacities**
 - **“My well went dry!”**

Steady-State Water Balance with Pumping



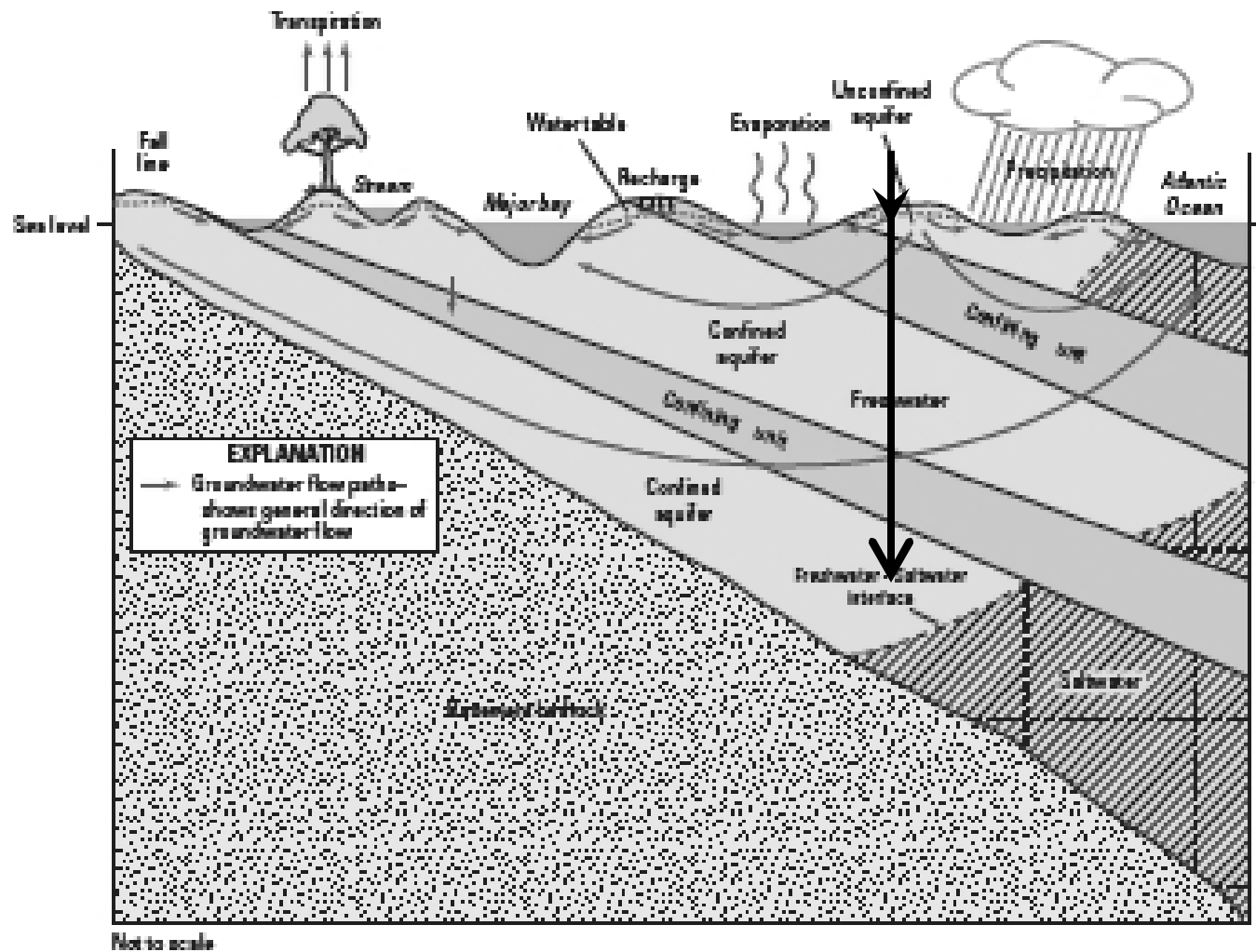


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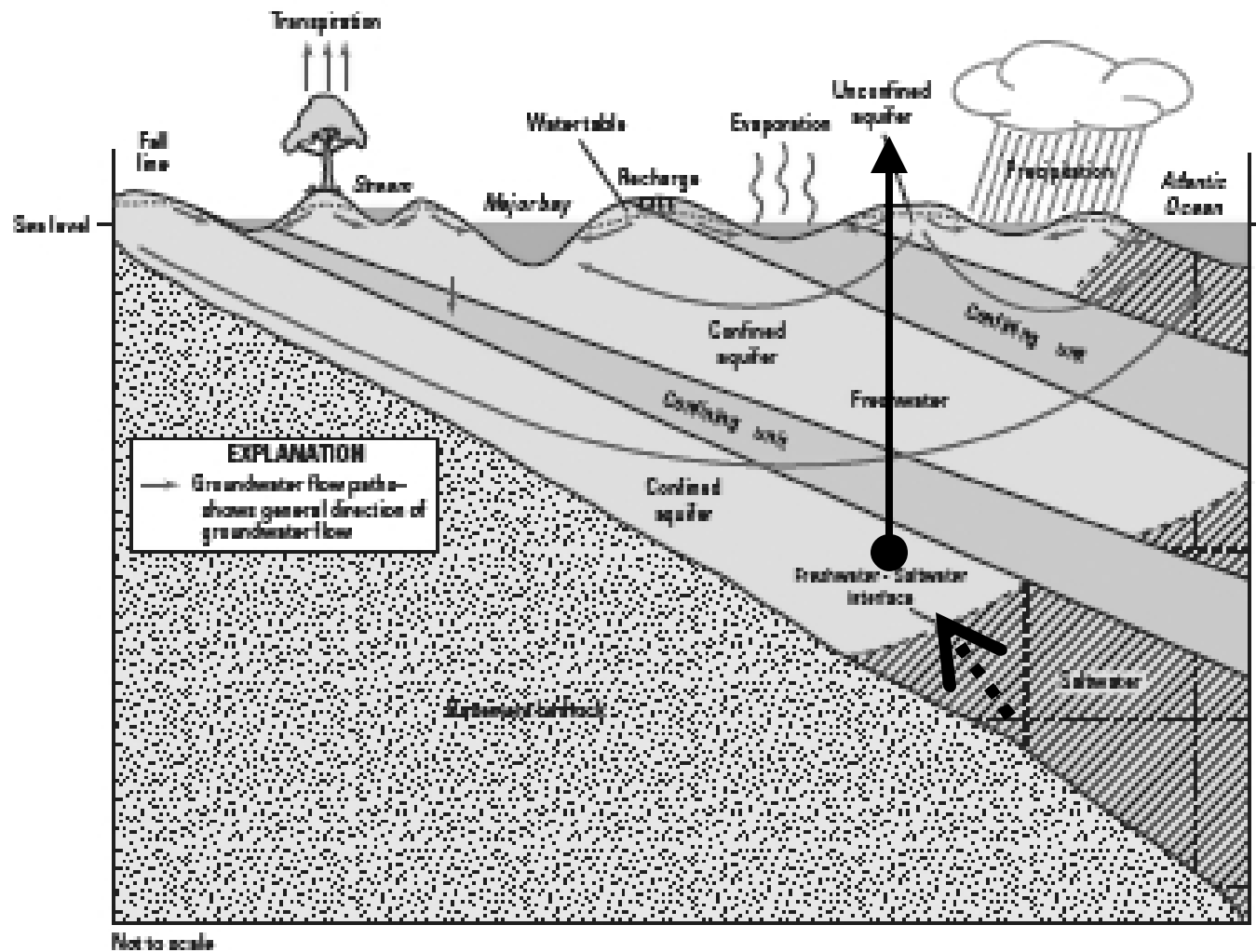


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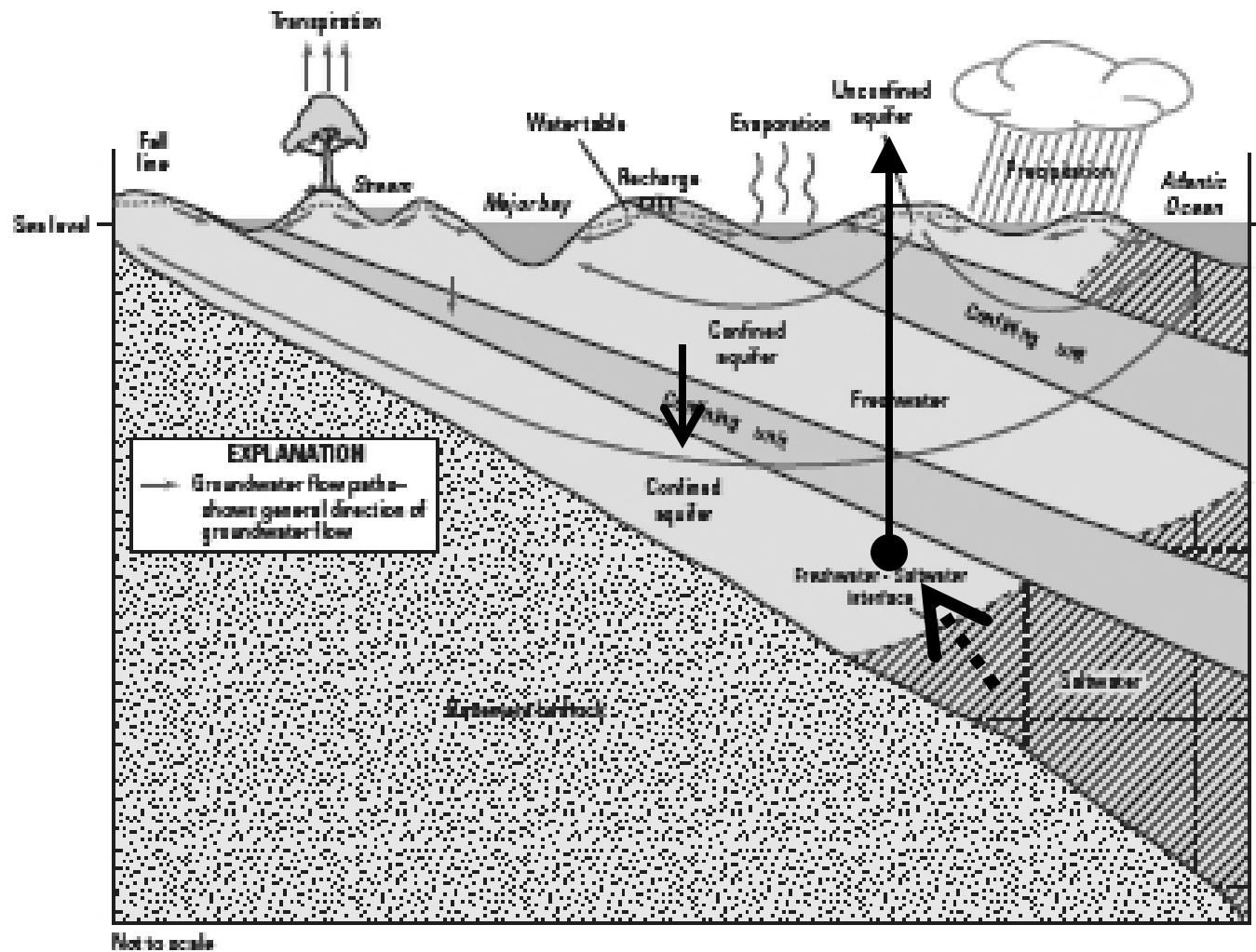


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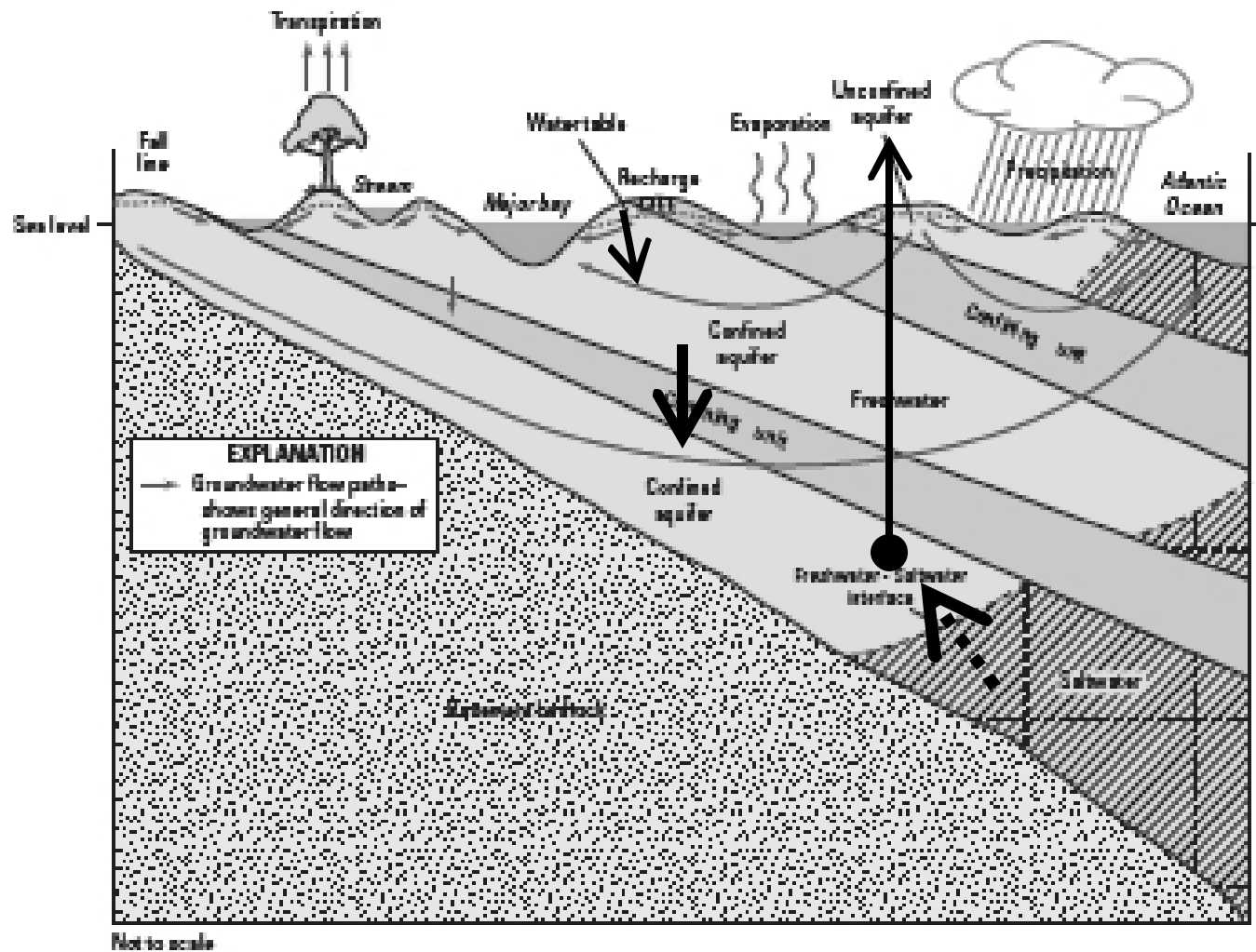


Figure 6. Generalized predevelopment groundwater flow patterns in the Coastal Plain aquifer system (modified from Leahy and Martin, 1993).

Leaky Aquifer Movie

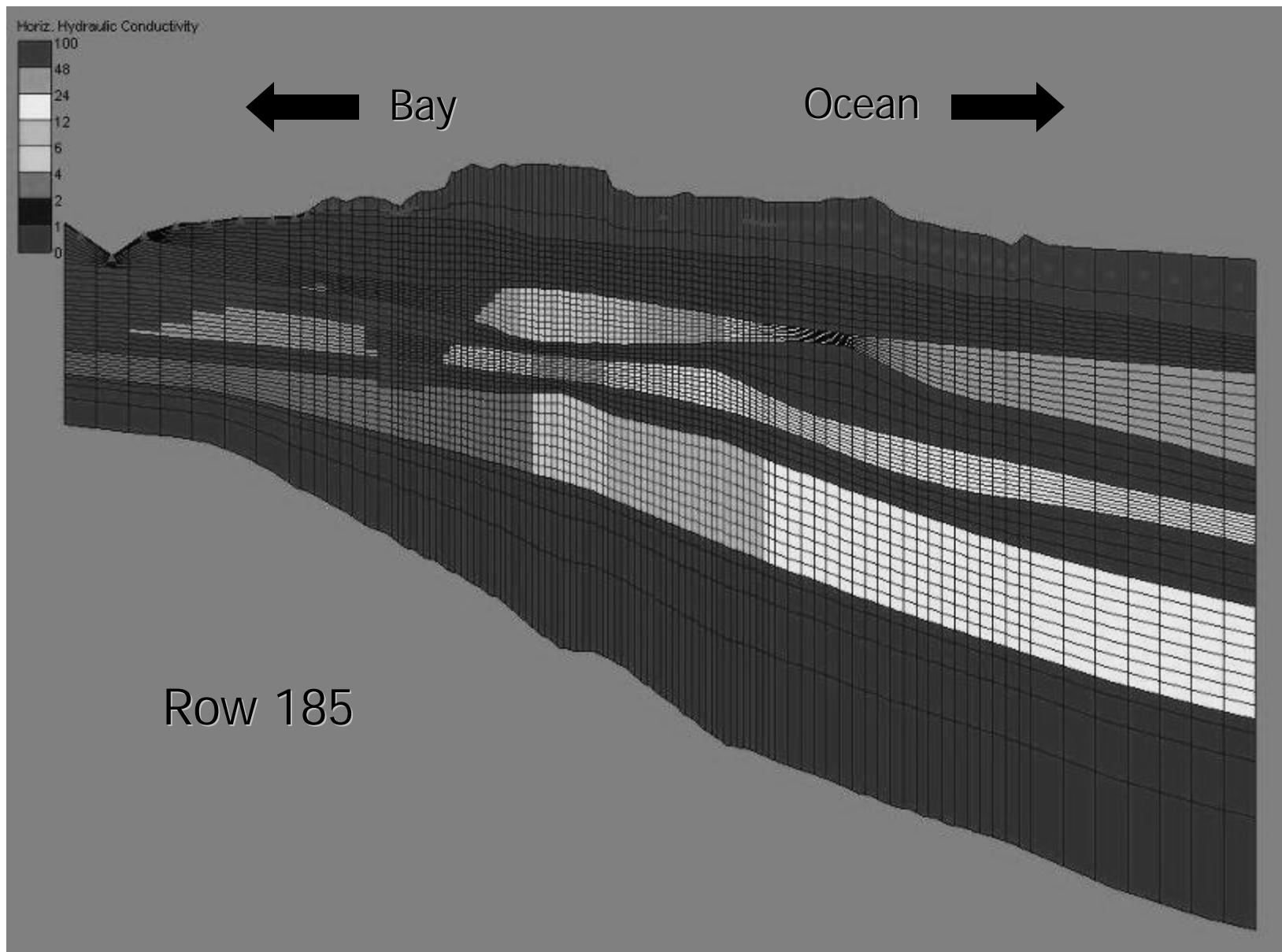
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Groundwater Modeling

- **Models Generalize**
 - **Extrapolate what we know**
 - **Rely on math that describes ‘the Ideal’**
 - **Regional models rely on calculus to simulate changes in the aquifer system by solving a matrix of equations simultaneously and iteratively.**



Groundwater Modeling

- **Models in the Permit Process**
 - **Sustainability**
 - **80% Criterion**
 - **Critical Cell Violations**
 - **Salt Water Intrusion**
 - **Mitigation Area**

Purpose of Technical Evaluation

Mission #1

- ***Permit issuance – protection of existing users and sustainability of the ground water resources***
 - **“The board shall issue a ground water withdrawal permit when it is demonstrated, by a complete application and the board's technical evaluation, to the board's satisfaction that the maximum safe supply of ground water will be preserved and protected for all other beneficial uses and that the applicant's proposed withdrawal will have no significant unmitigated impact on existing ground water users or the ground-water resource.”**

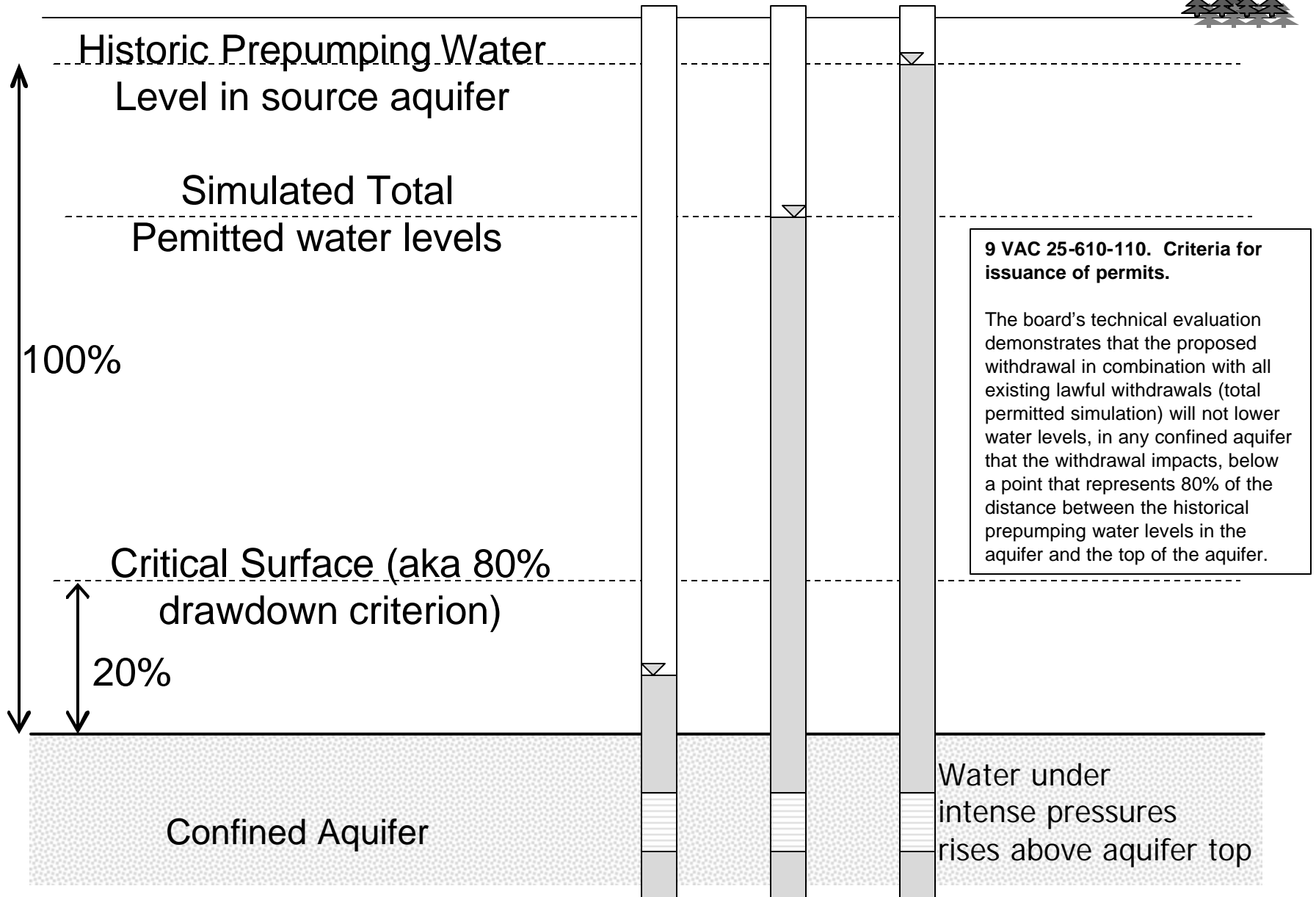
Evaluation of Allowable Drawdown (80%) and Adverse Changes to Water Quality

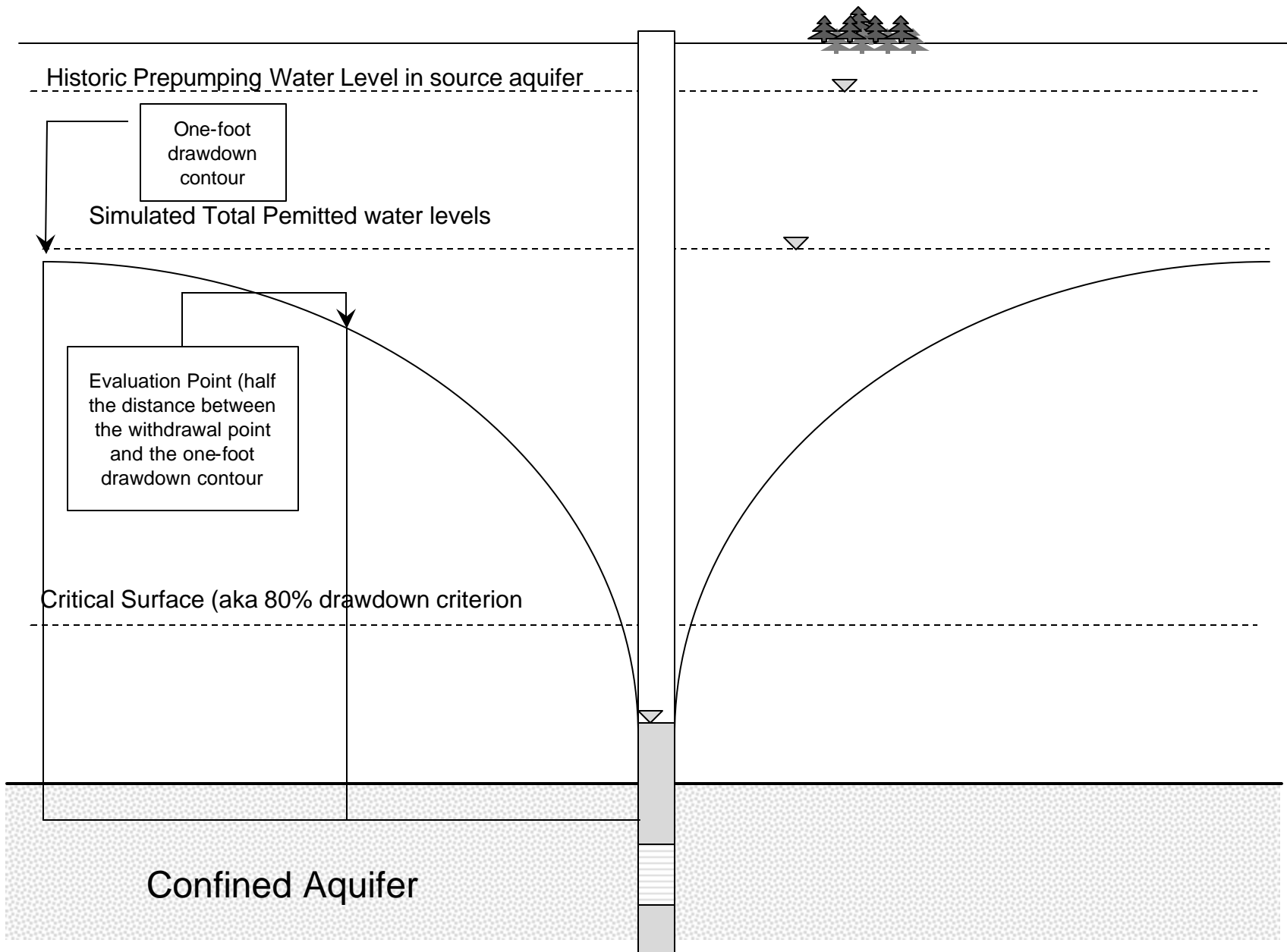
***Must consider all lawful withdrawals
at stabilized conditions – regional
models utilized.***

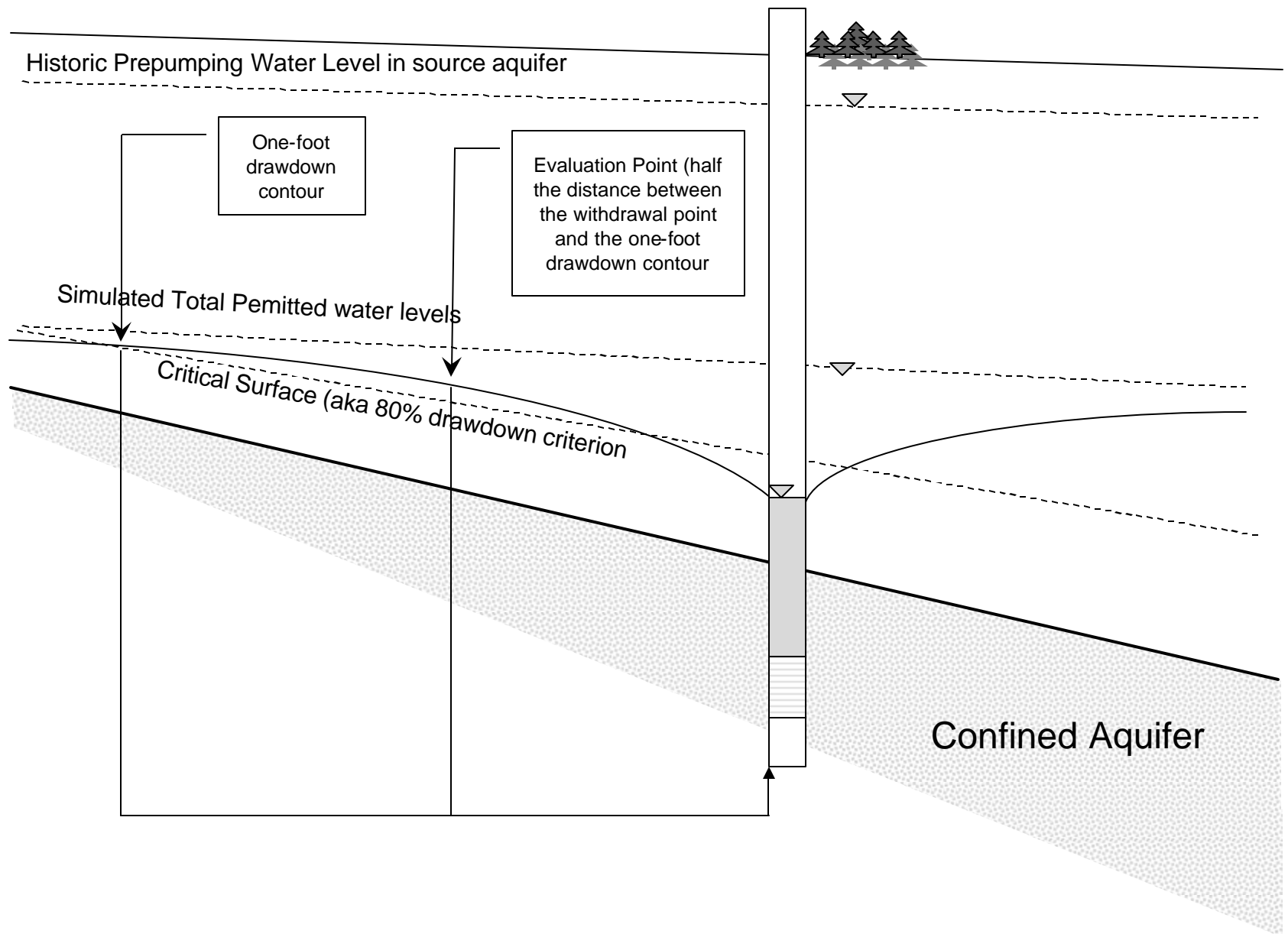
80% Drawdown Surface aka Critical Surface

***Simulating maximum permitted
withdrawal scenario at stabilized
(equilibrium) conditions.***

aka “Total Permitted”



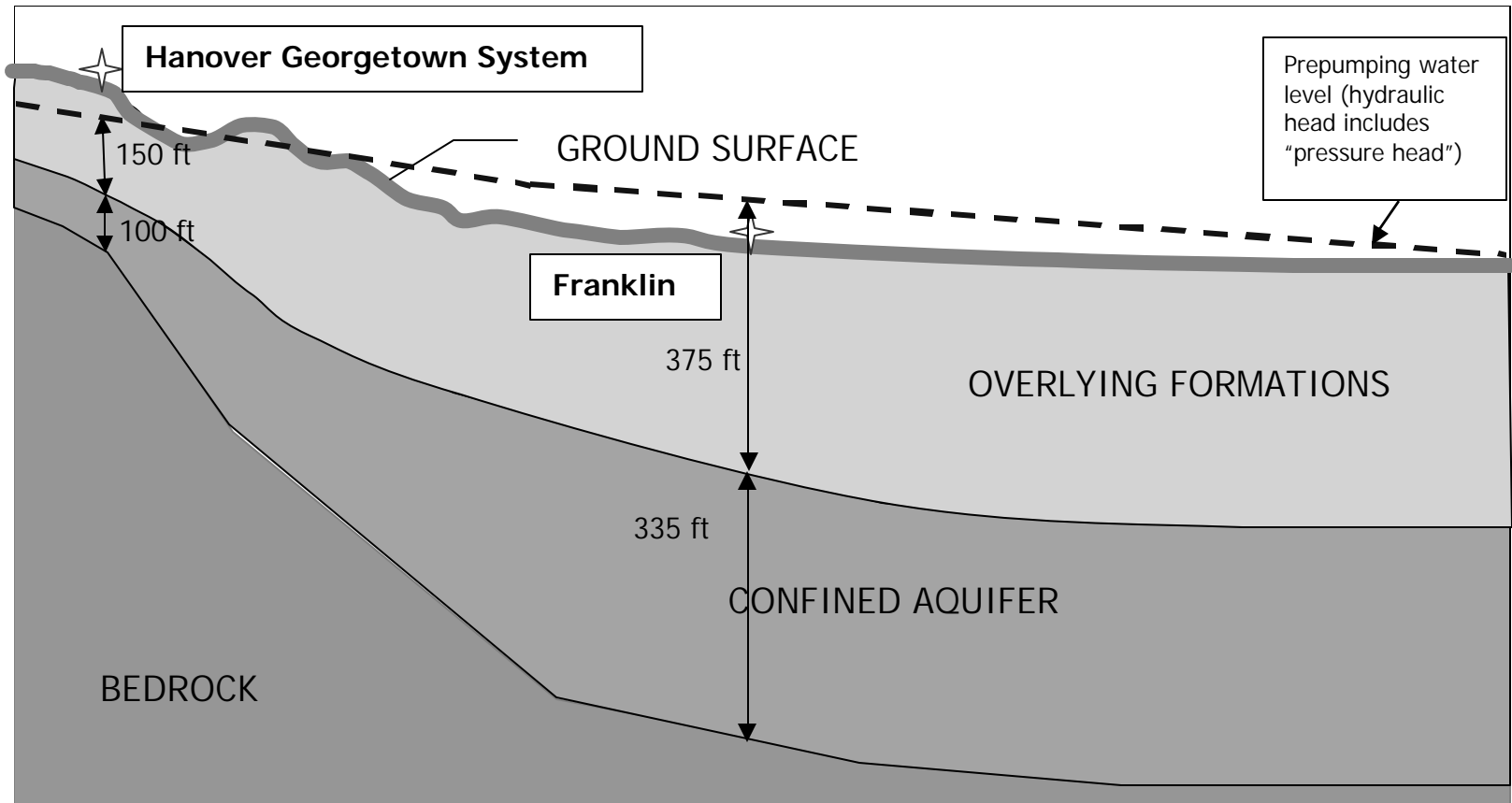




The Virginia Coastal Plain consists of an eastward dipping and thickening wedge of generally unconsolidated sands and clays. The sediments range in thickness from more than 6,000 feet beneath the northeastern part of the Eastern Shore Peninsula to a feather edge along the Fall Line.

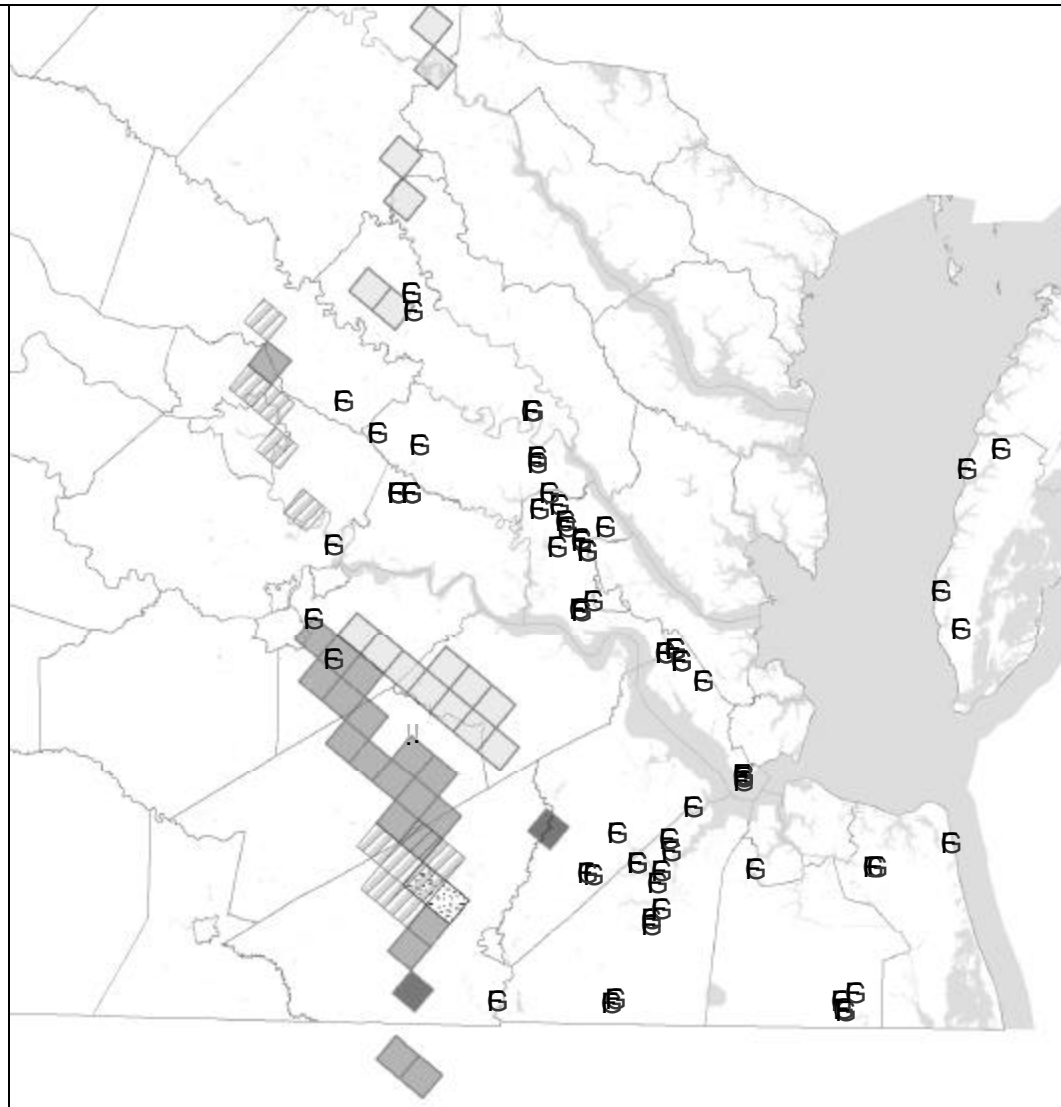
WEST








EAST




Critical Violations with aquifer test locations

1



-  Aquifer Tests
-  Town of Waverly Wells
-  Middle Potomac Critical Cells
-  Upper Potomac Critical Cells
-  Aquia Aquifer Critical Cells
-  CPP Critical Cells
-  Yorktown-Eastover Critical Cells

 Miles
0 4.5 9 18 27 36

Purpose of Technical Evaluation

Mission #2

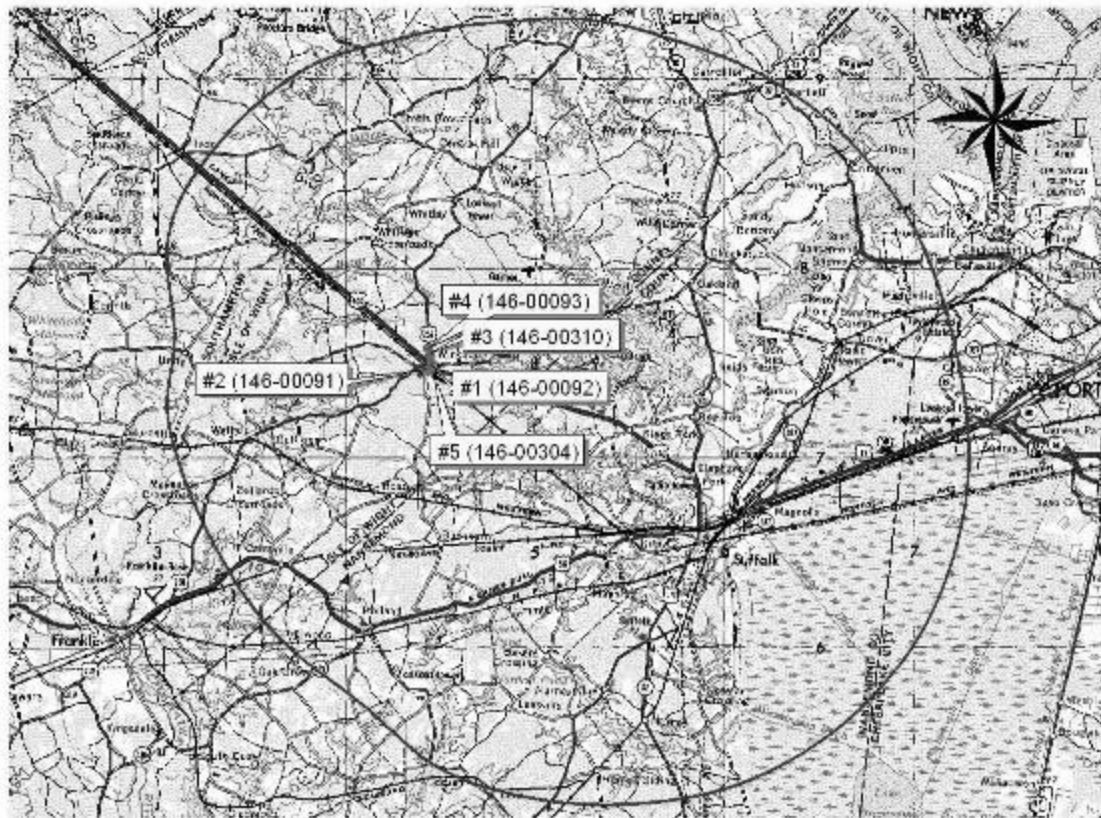
➤ *Specification of Mitigation Area*

- **“The board shall issue a ground water withdrawal permit when it is demonstrated, by a complete application and the board's technical evaluation, to the board's satisfaction that the maximum safe supply of ground water will be preserved and protected for all other beneficial uses and that the applicant's proposed withdrawal will have no significant unmitigated impact on existing ground water users or the ground-water resource.”**

AOI

- *Area of Impact or AOI*

Town of Windsor - Windsor Public Water System Area of Impact - Upper Potomac Aquifer

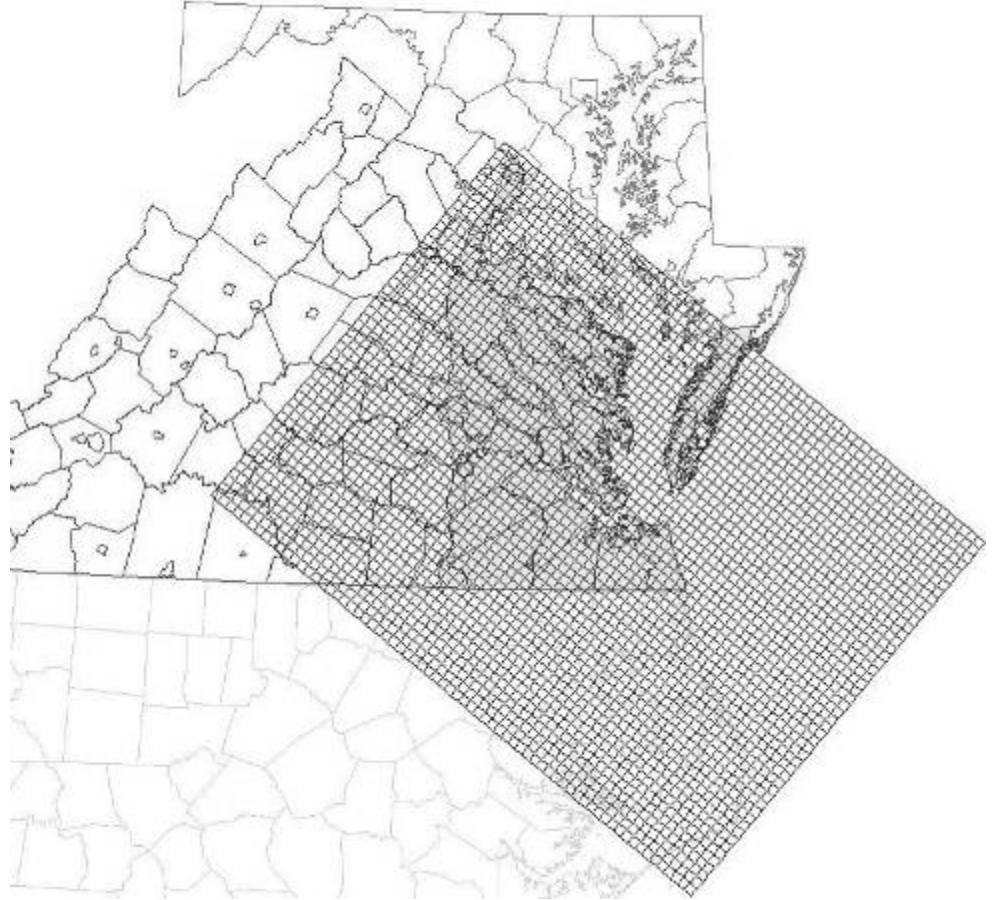


8 0 8 16 Miles

- “...to determine the areas of any aquifers that will experience at least one foot of water level declines due to the proposed withdrawal and may evaluate the potential for the proposed withdrawal to cause salt water intrusion into any portions of any aquifers or the movement of waters of lower quality to areas where such movement would result in adverse impacts on existing ground water users or the ground water resource.”

Virginia Coastal Plain Model

- *Developed by USGS in early 80's*
- *Refined and GIS developed in early 90's*
- *Simulates 9 confined aquifers + constant head water table*
- *Cell sides 3.5 miles*
- *MODFLOW*

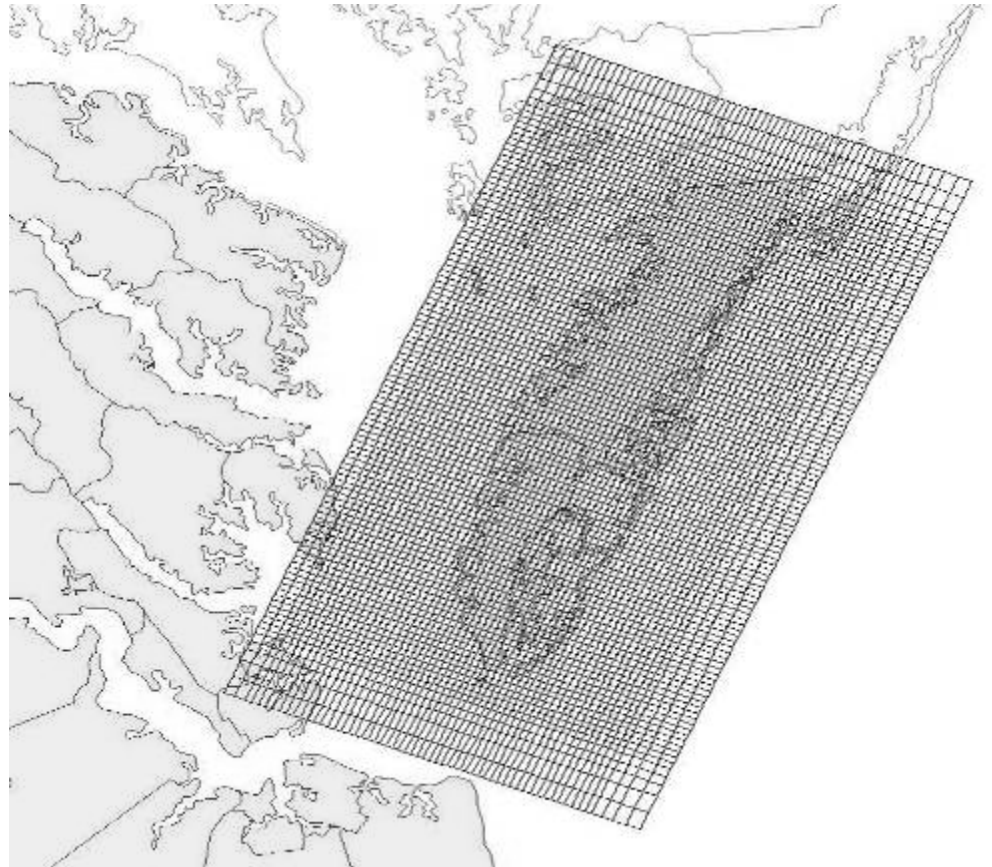


VCPM Annual Simulations

- ***Simulation of all reported groundwater use***
 - Identifies data gaps/defines data managed
 - Compare to actual water levels
- ***Total Permitted***
 - To develop baseline for regulatory requirement to assess impacts for proposed withdrawals in combination with all existing lawful withdrawals
 - To identify areas where water levels are predicted to fall below 80% drawdown criterion
 - Authority for obtaining data in WD regulated areas

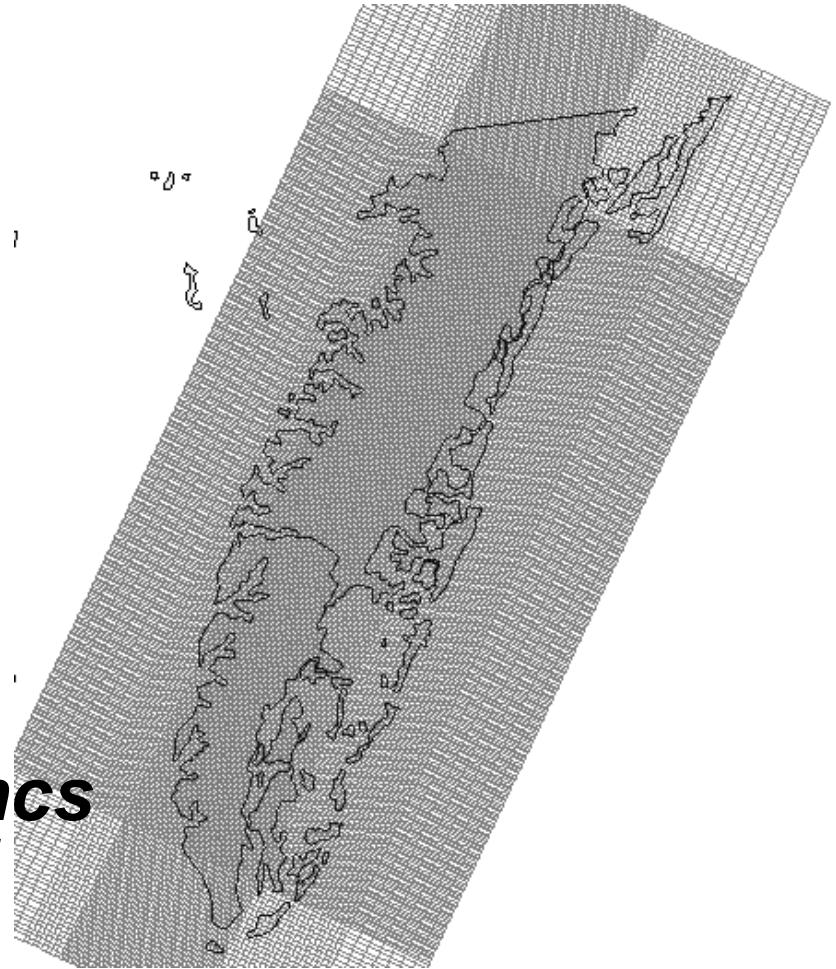
Eastern Shore Sharp Model

- *Developed by USGS in late 90's to look at several pumping scenarios*
- *Simulates the Yorktown aquifer as 3 confined aquifers*
- *Simulates salt water boundary as a sharp interface*
- *Cell side 0.5 miles*
- *USGS SHARP*



Sanford Seawat Model

- *Density dependent flow – water quality*
- *Smaller grid size*
- *Includes paleochannels*
- *Includes agriculture*
- *Includes MD*
- *Includes estimate of domestic use*
- *Revised Shore model syncs model layers with natural system geometry.*



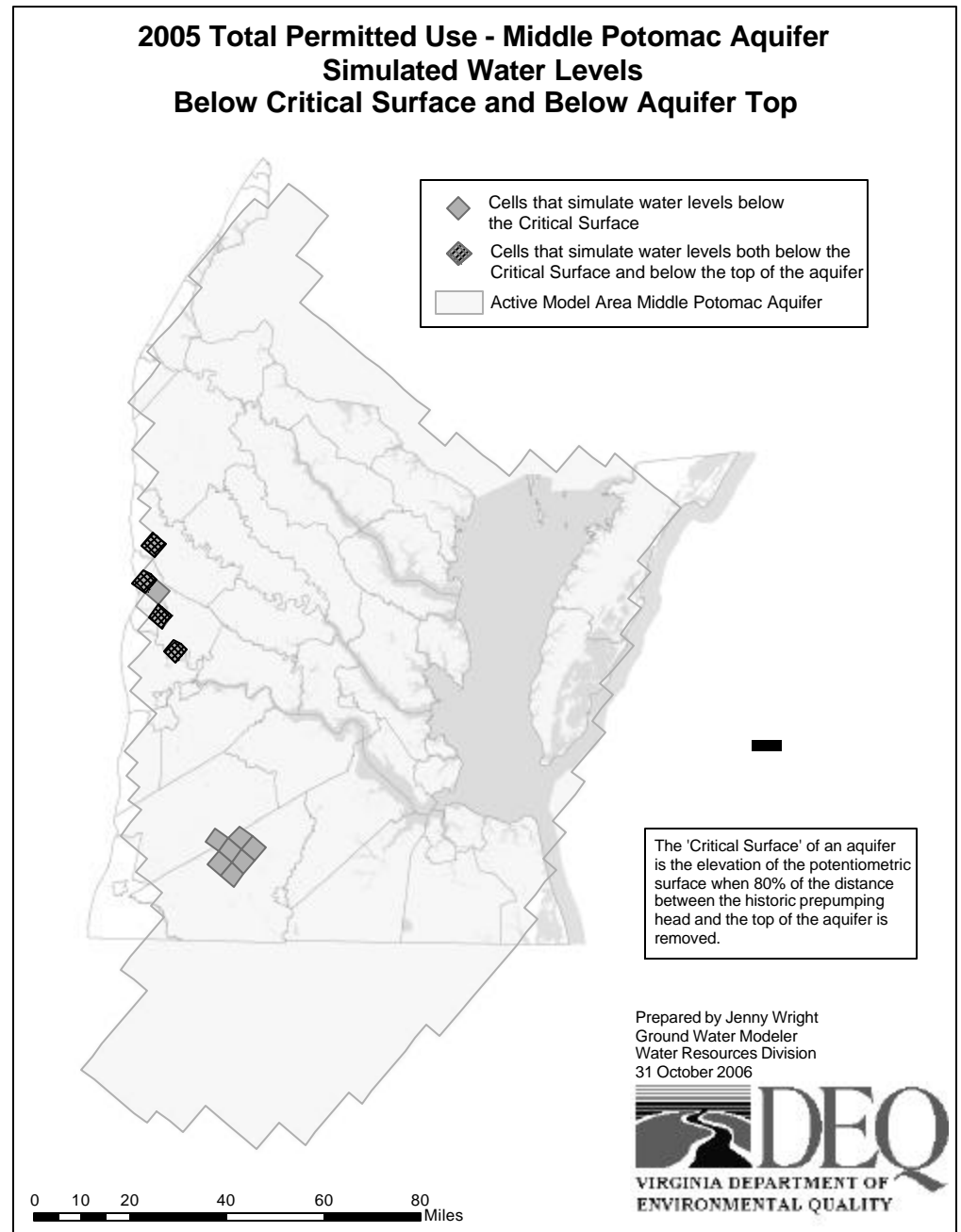
Groundwater Modeling

- **Current State of the Modeled System**
- **Current State of the Actual System
(field observations)**

2005 Total Permitted Simulation

Middle Potomac Aquifer

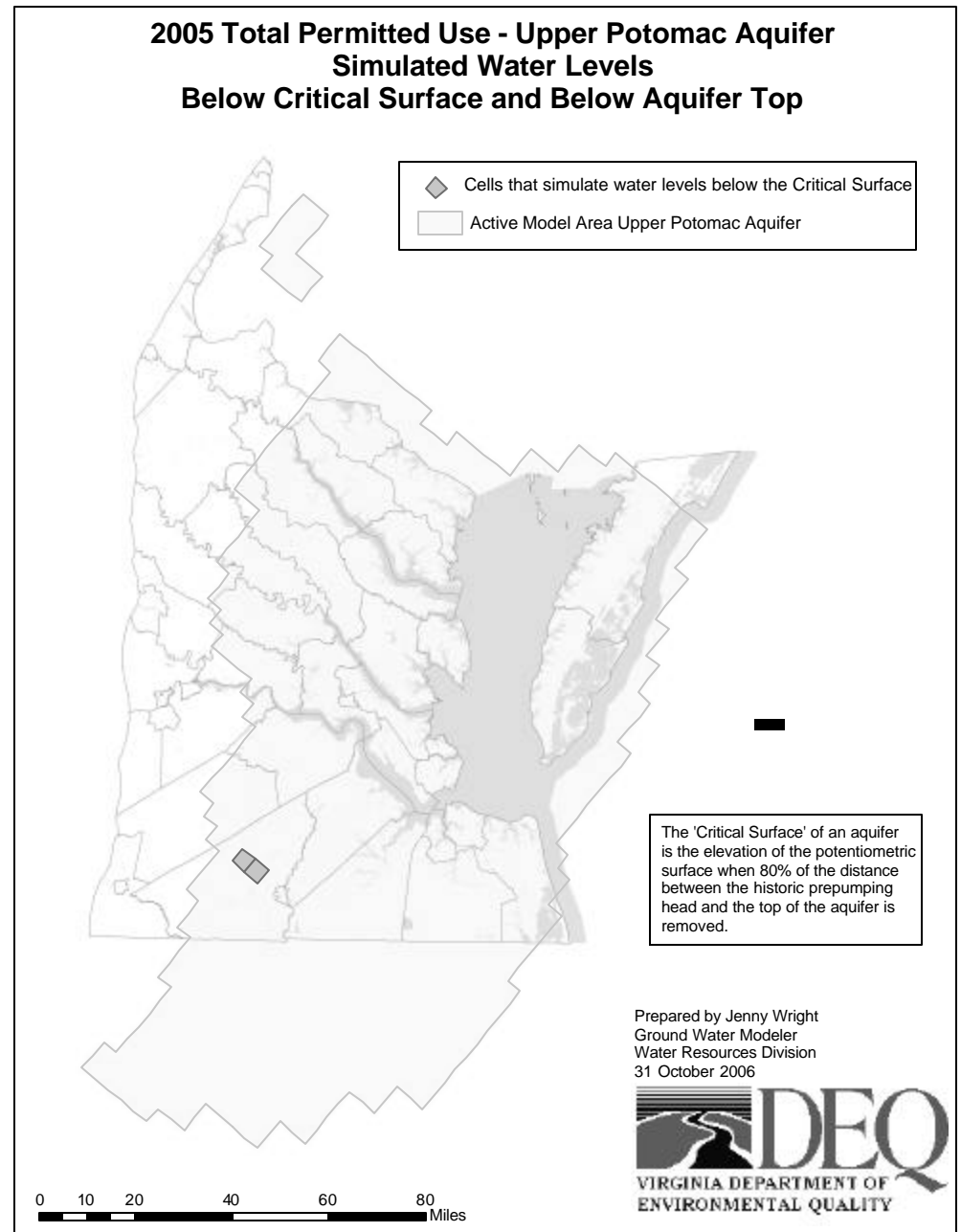
Critical Surface Violations



2005 Total Permitted Simulation

Upper Potomac Aquifer

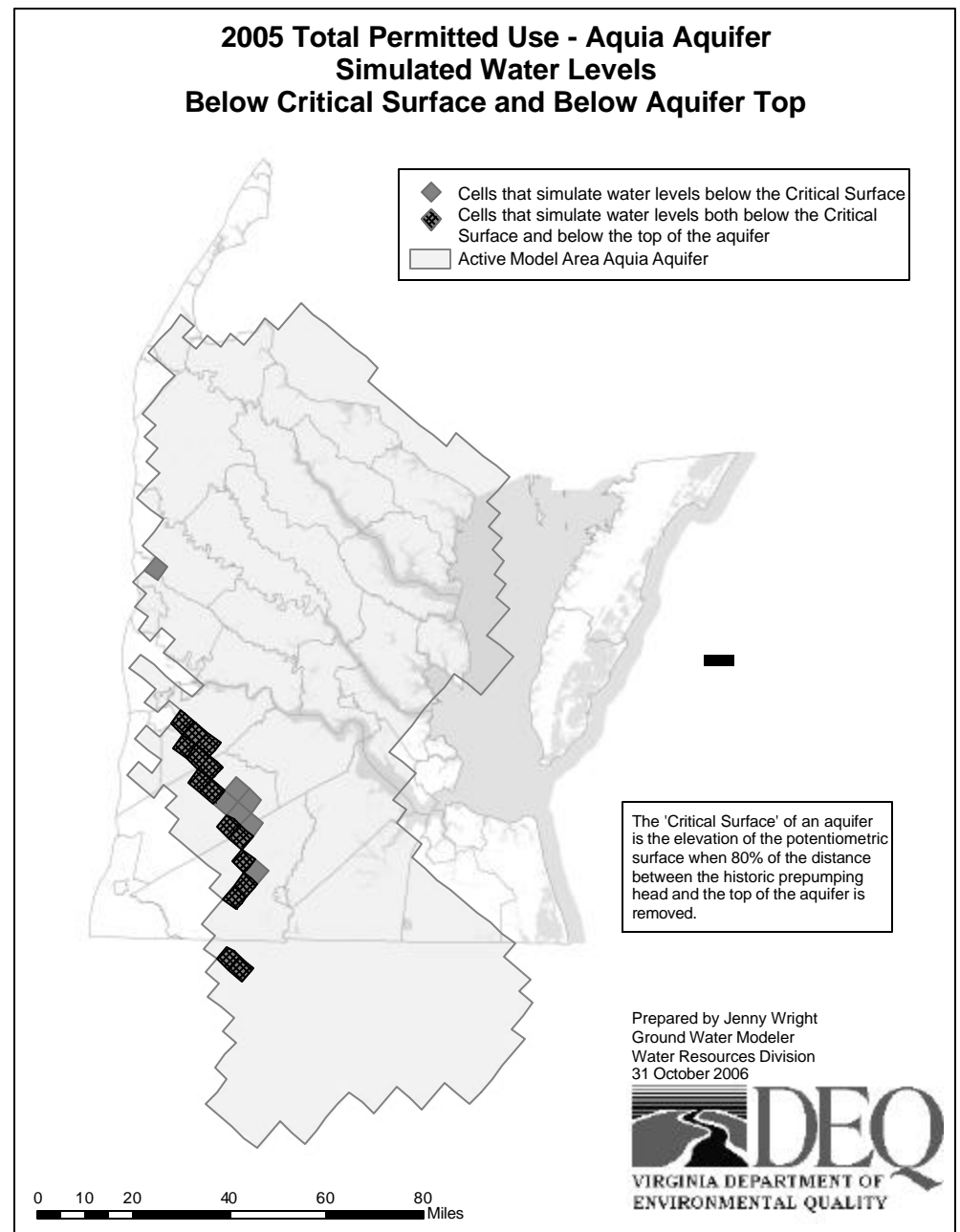
Critical Surface Violations



2005 Total Permitted Simulation

Aquia Aquifer

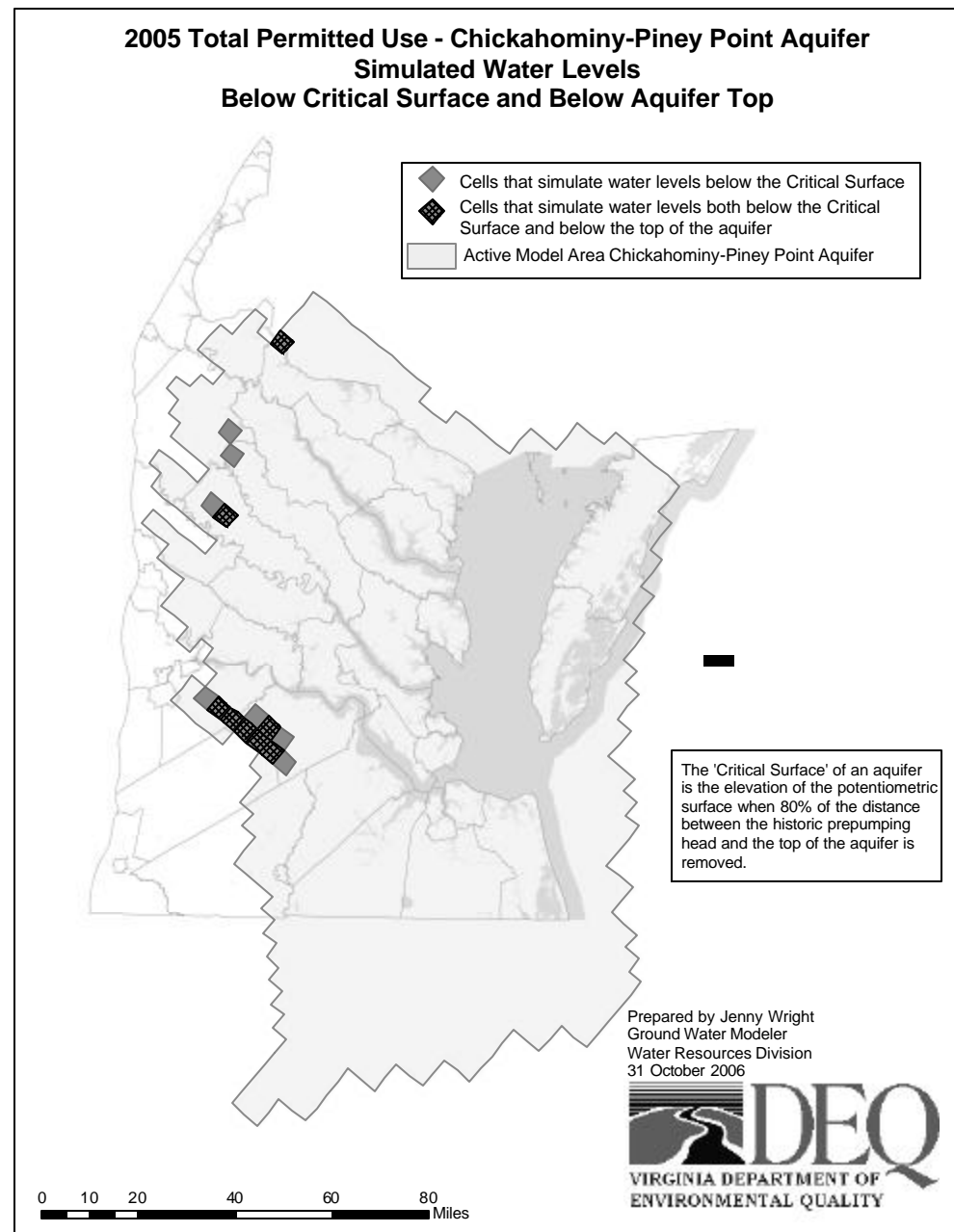
Critical Surface Violations



2005 Total Permitted Simulation

Chickahominy -Piney Point Aquifer

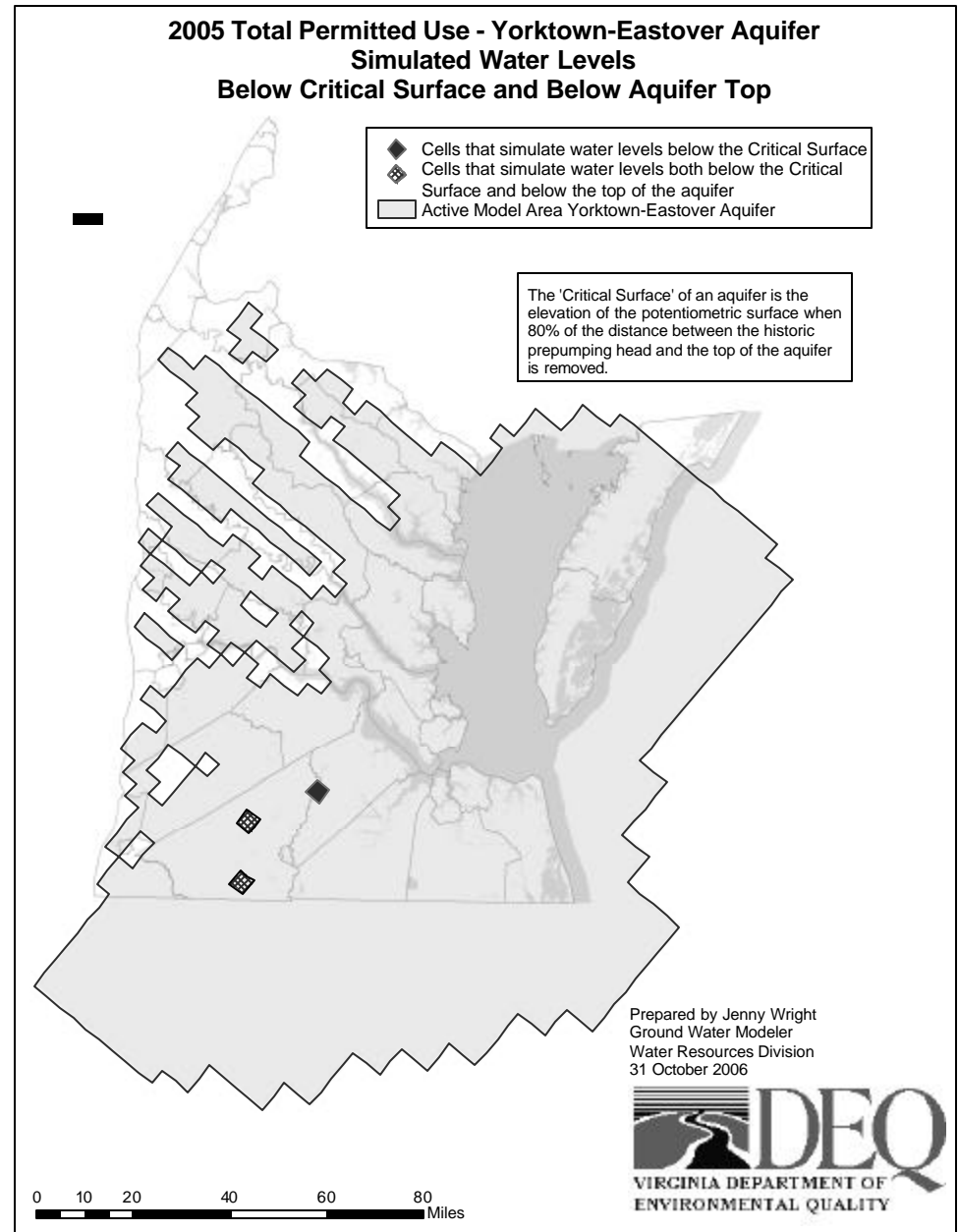
Critical Surface Violations



2005 Total Permitted Simulation

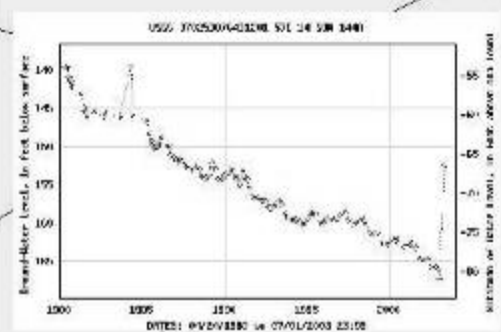
Yorktown-Eastover Aquifer

Critical Surface Violations

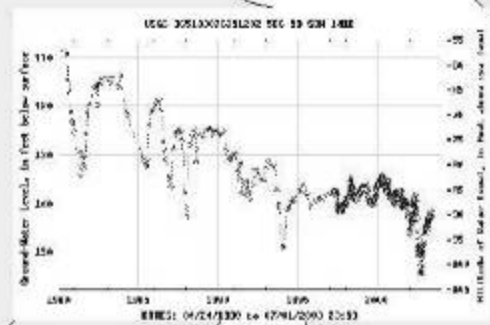


MOONLIGHT

ISLE OF WIGHT



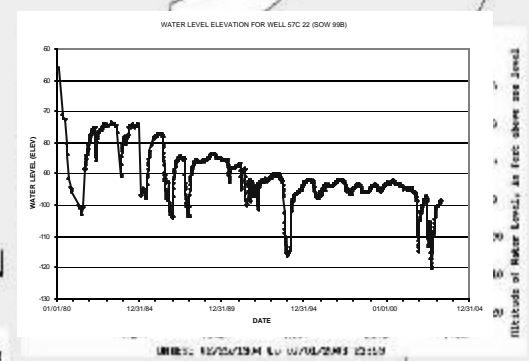
CHUCKATUCK



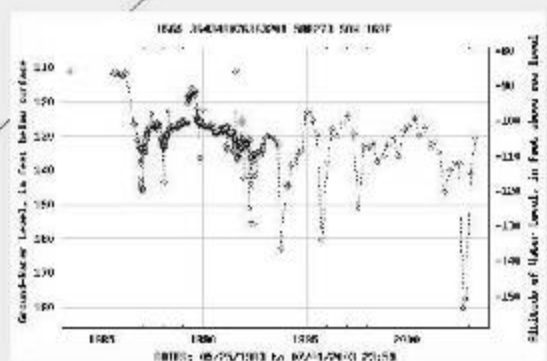
NORFOLK
PORTSMOUTH

WINDSOR CC

PRUDEN



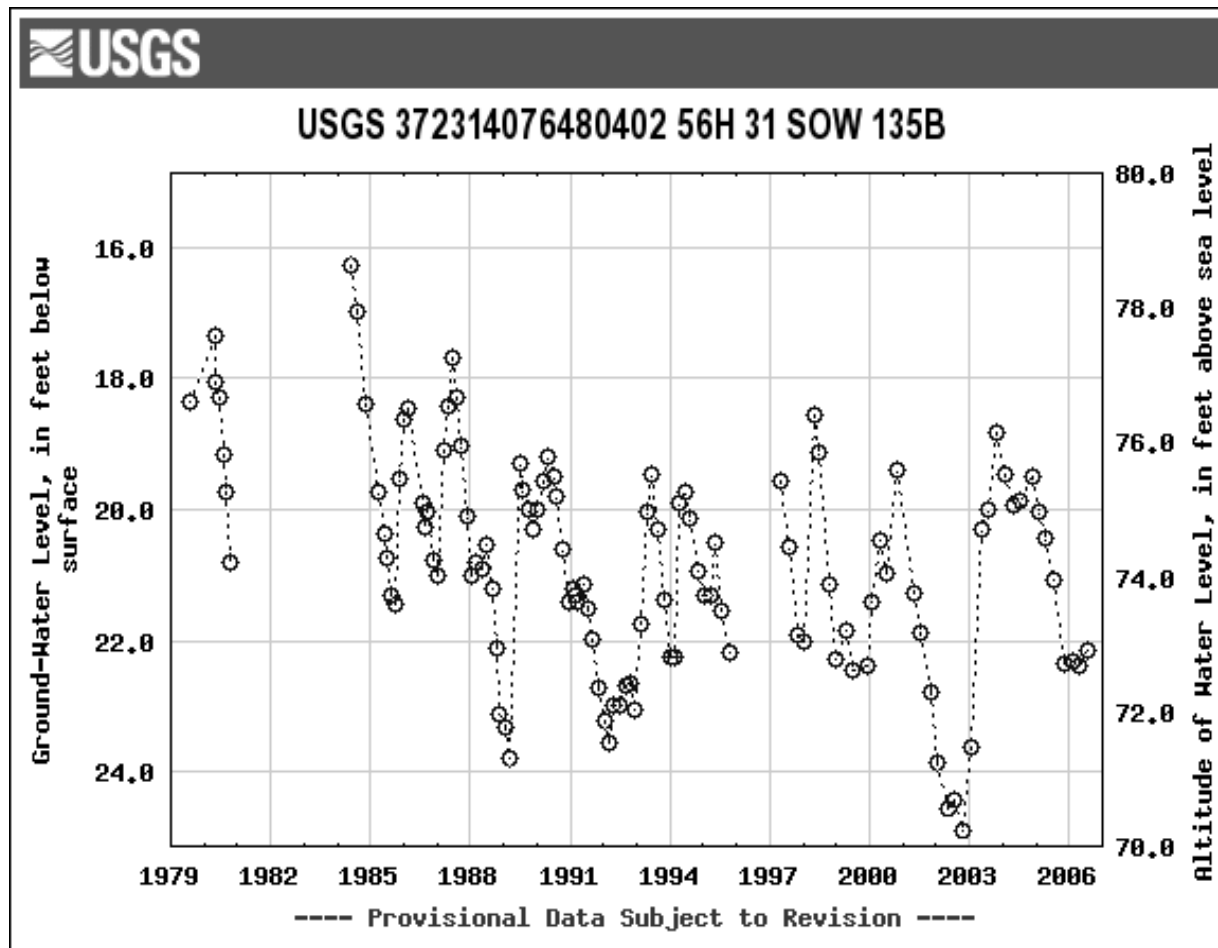
LAKE KILBY
SUFFOLK



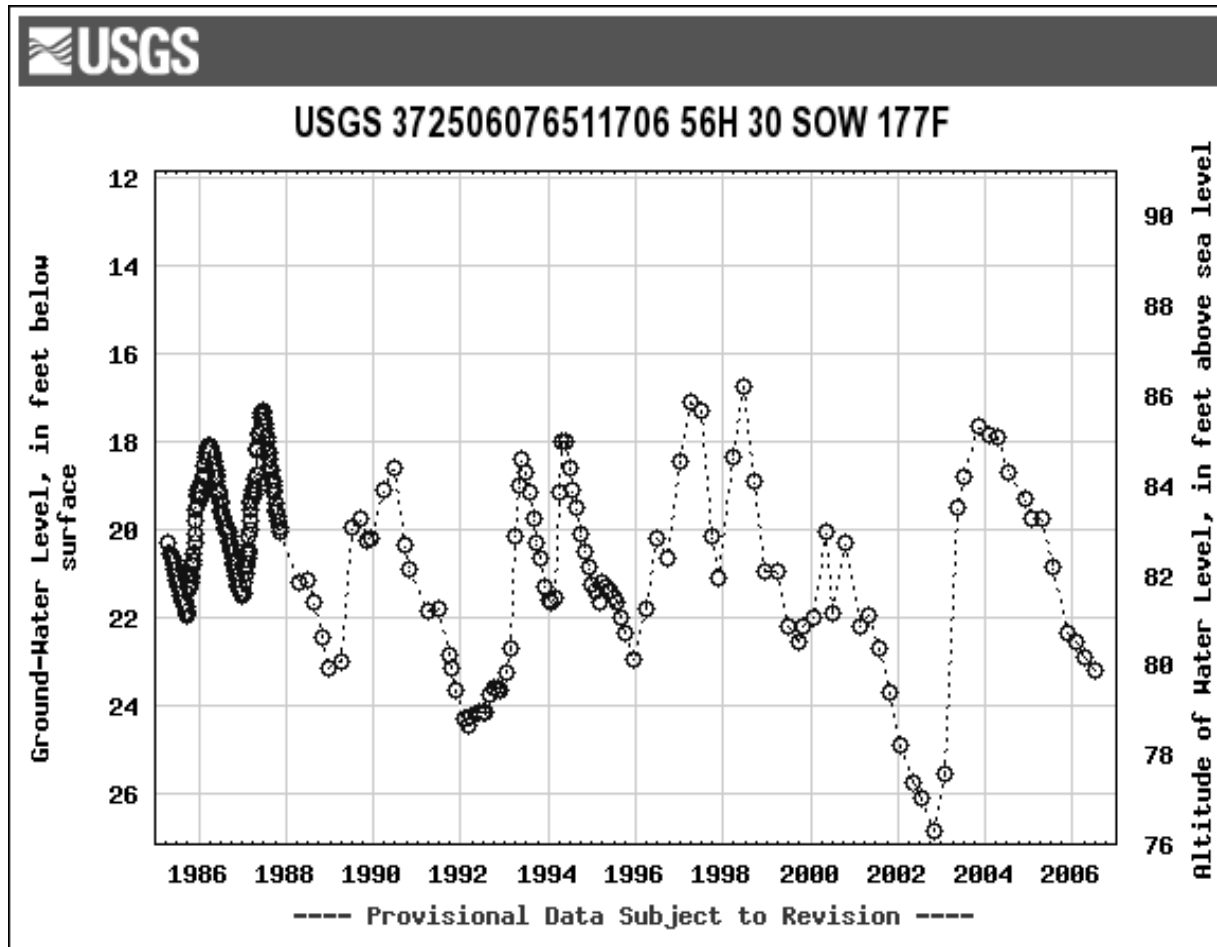
CHESAPEAKE

Toano

Shallow Water Table Aquifer

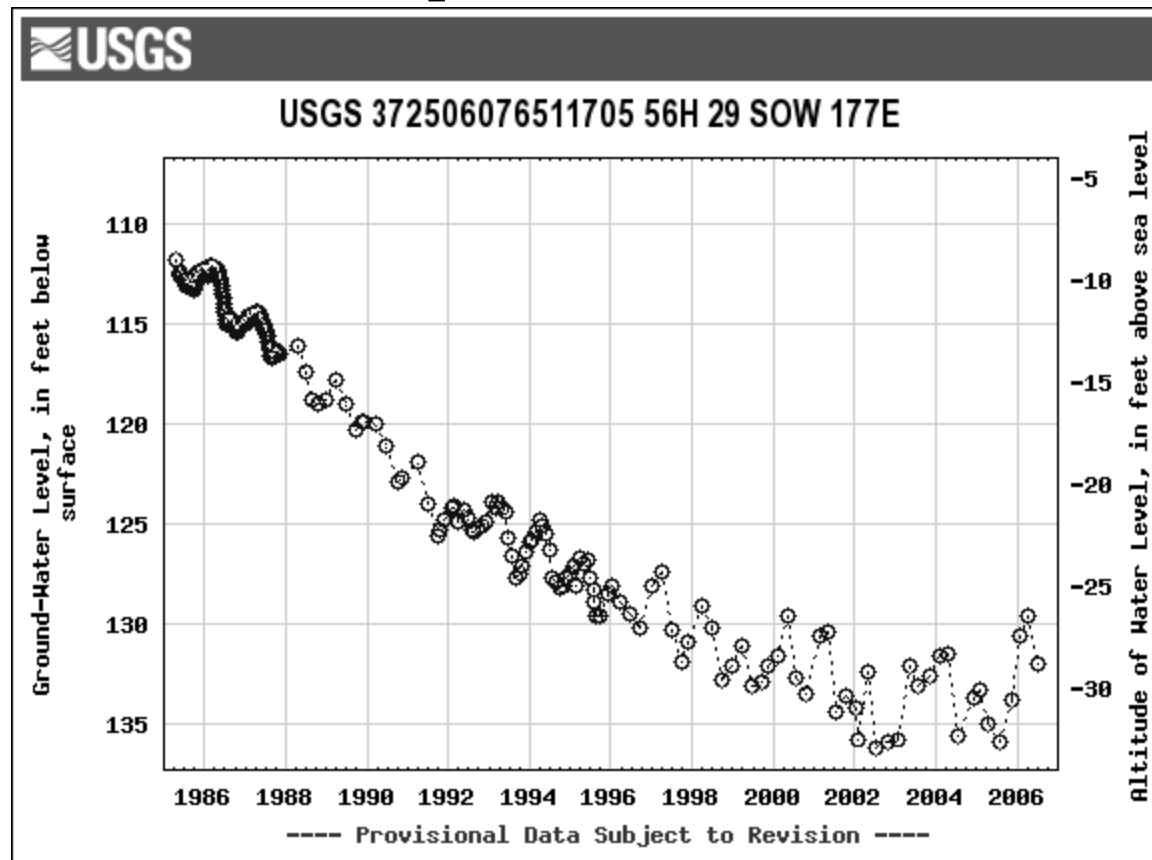


Barnes Road Yorktown-EastoverAquifer



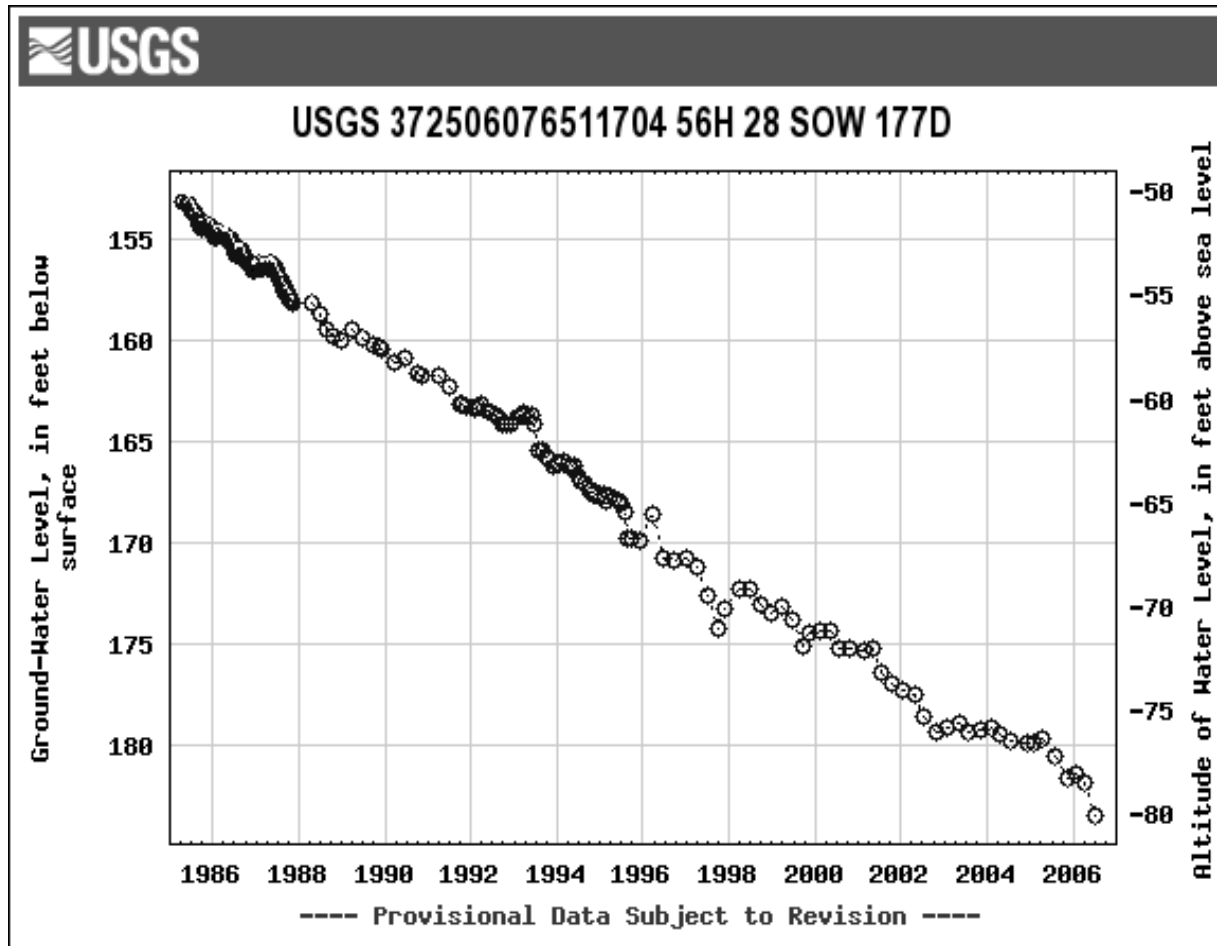
Top of the Yorktown-Eastover aquifer = 36 feet

Barnes Road Chickahominy-Piney Point Aquifer



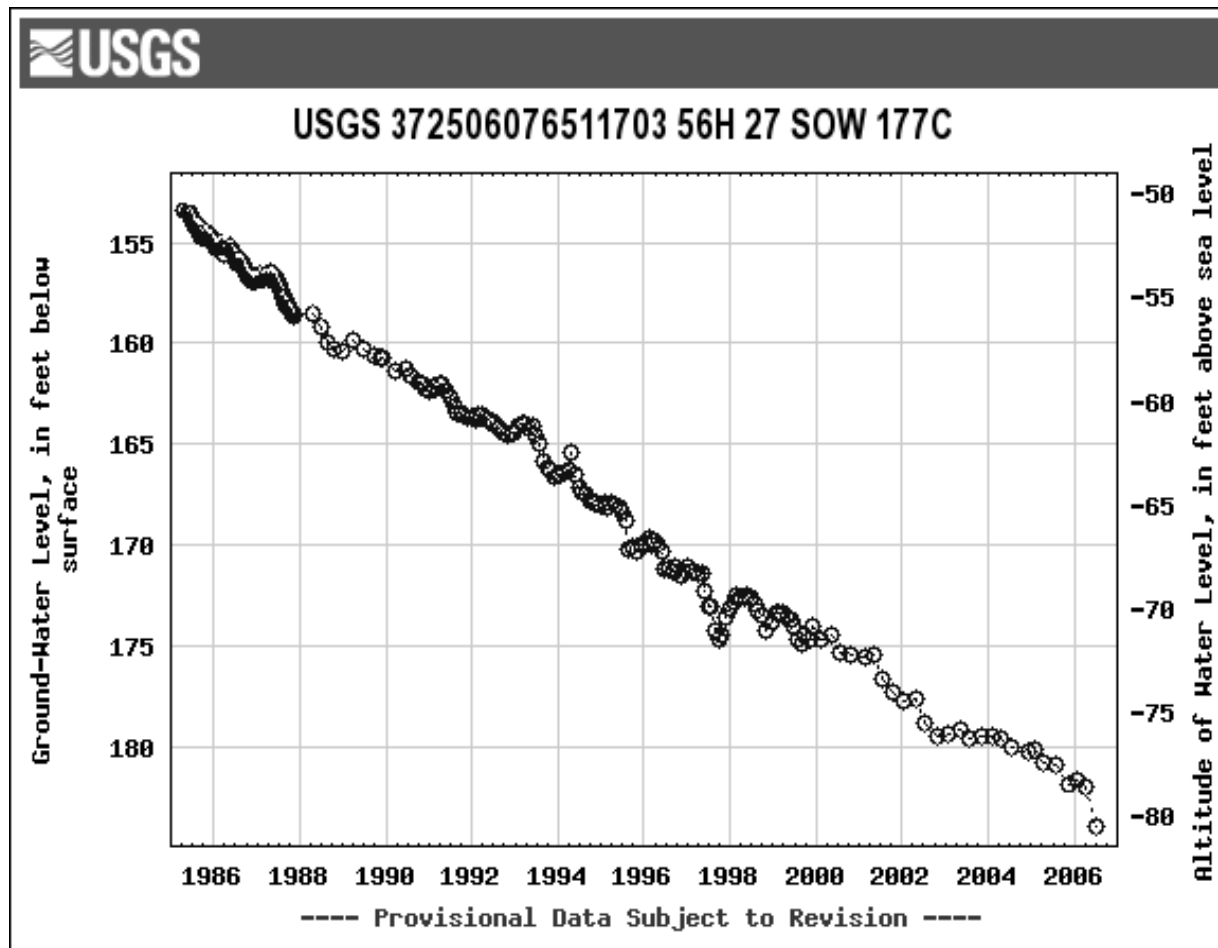
Top of the Chickahominy-Piney Point aquifer = 164 feet

Barnes Road Aquia Aquifer



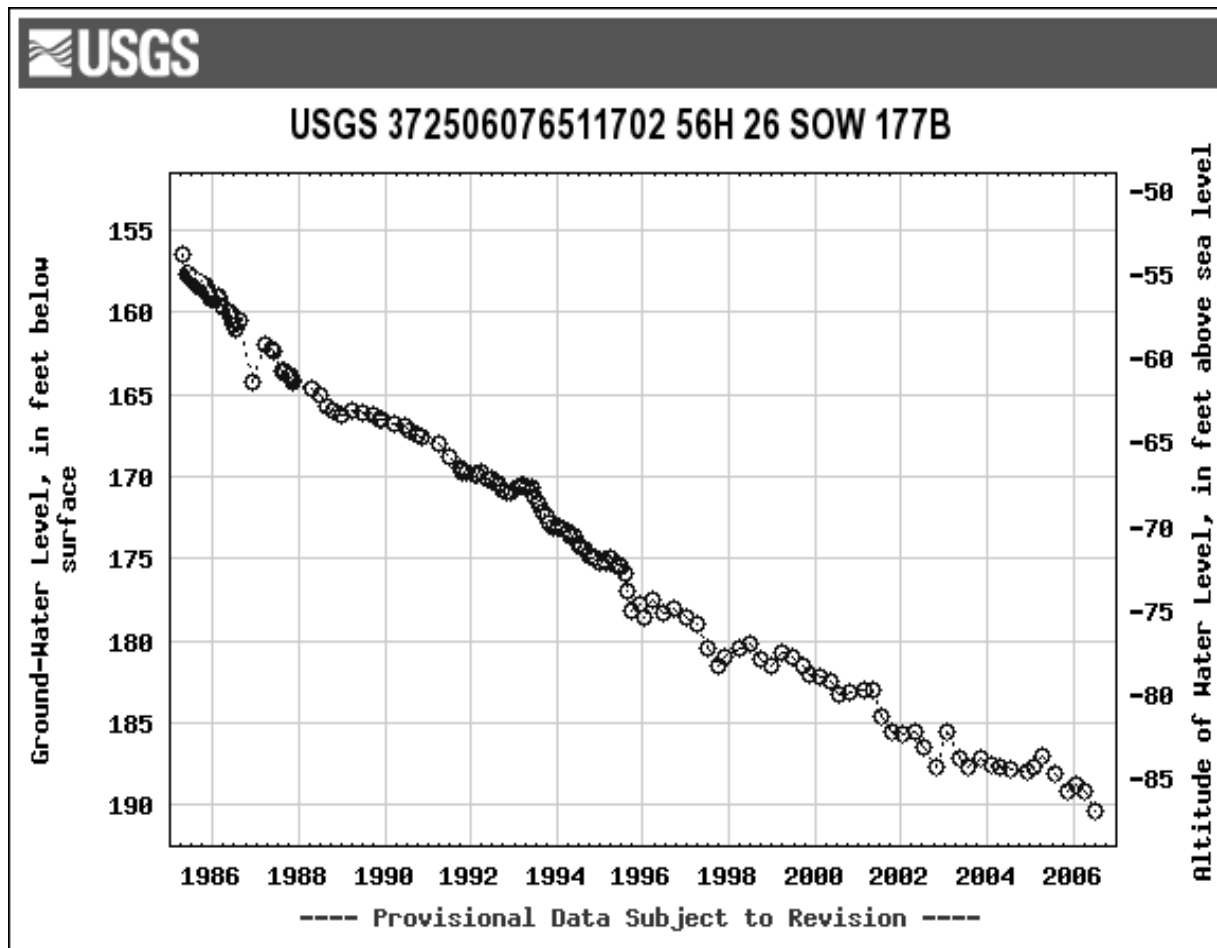
Top of the Aquia aquifer = 286 feet

Barnes Road upper Potomac Aquifer



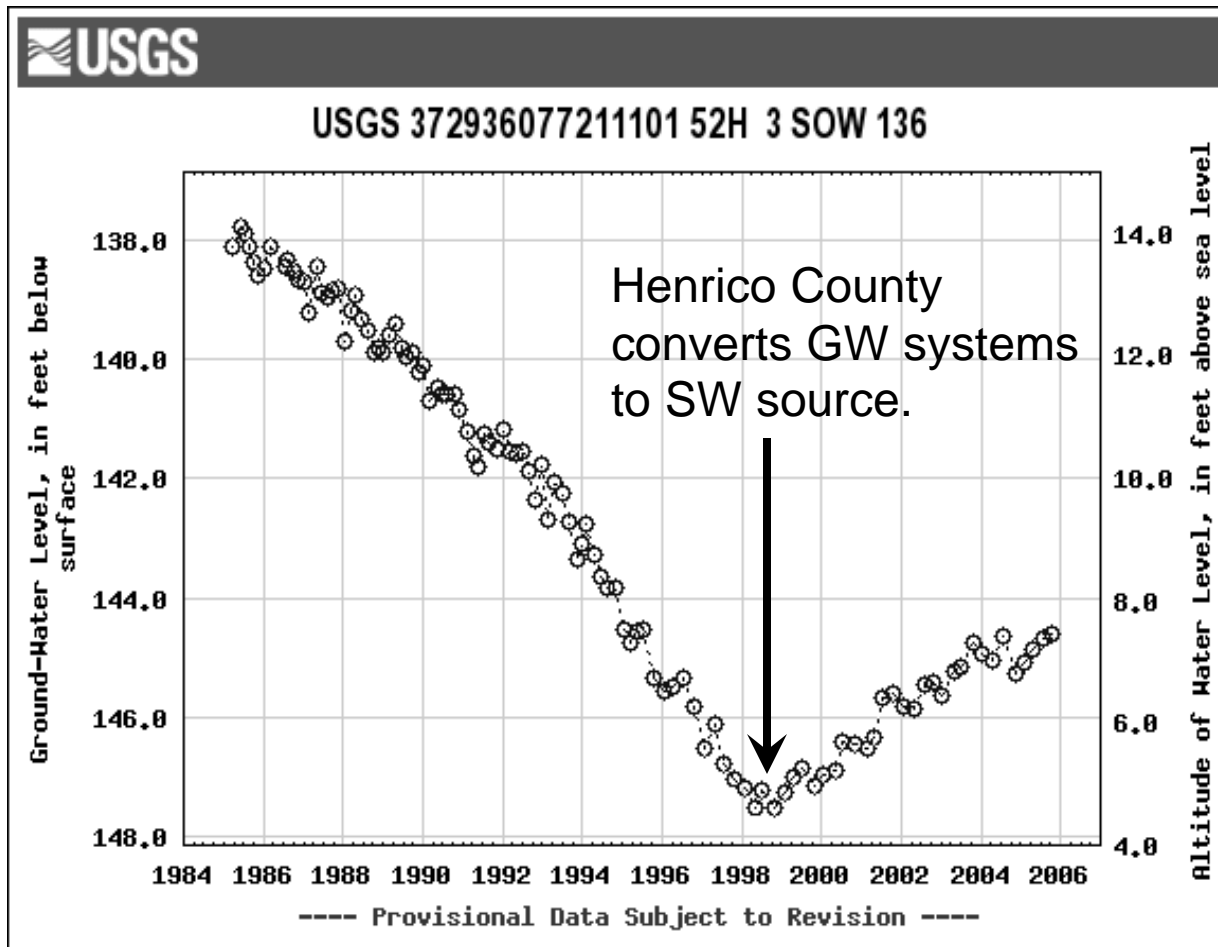
Top of the upper Potomac aquifer = 363 feet

Barnes Road middle Potomac Aquifer

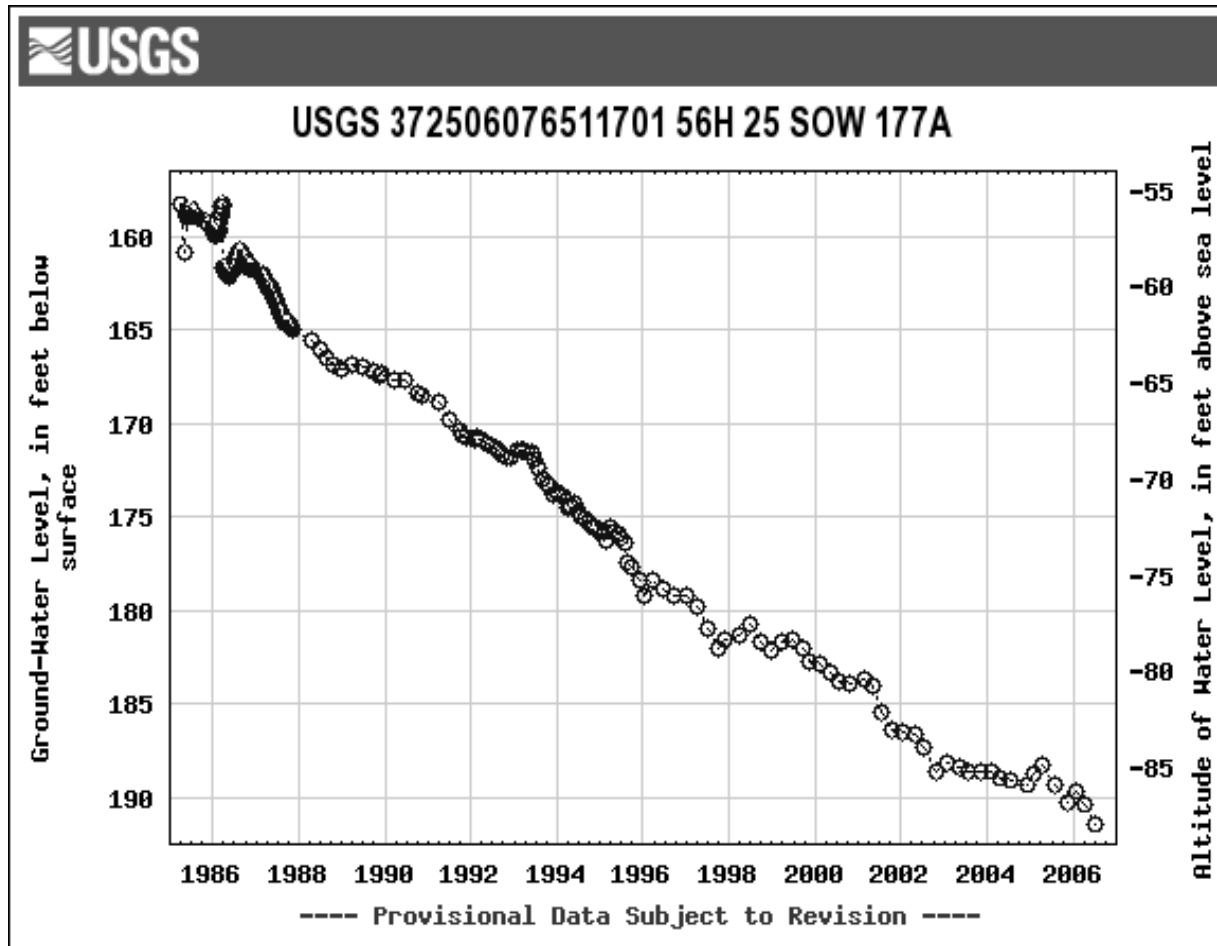


Top of the middle Potomac aquifer = 450 feet

Nabisco Henrico County middle Potomac Aquifer

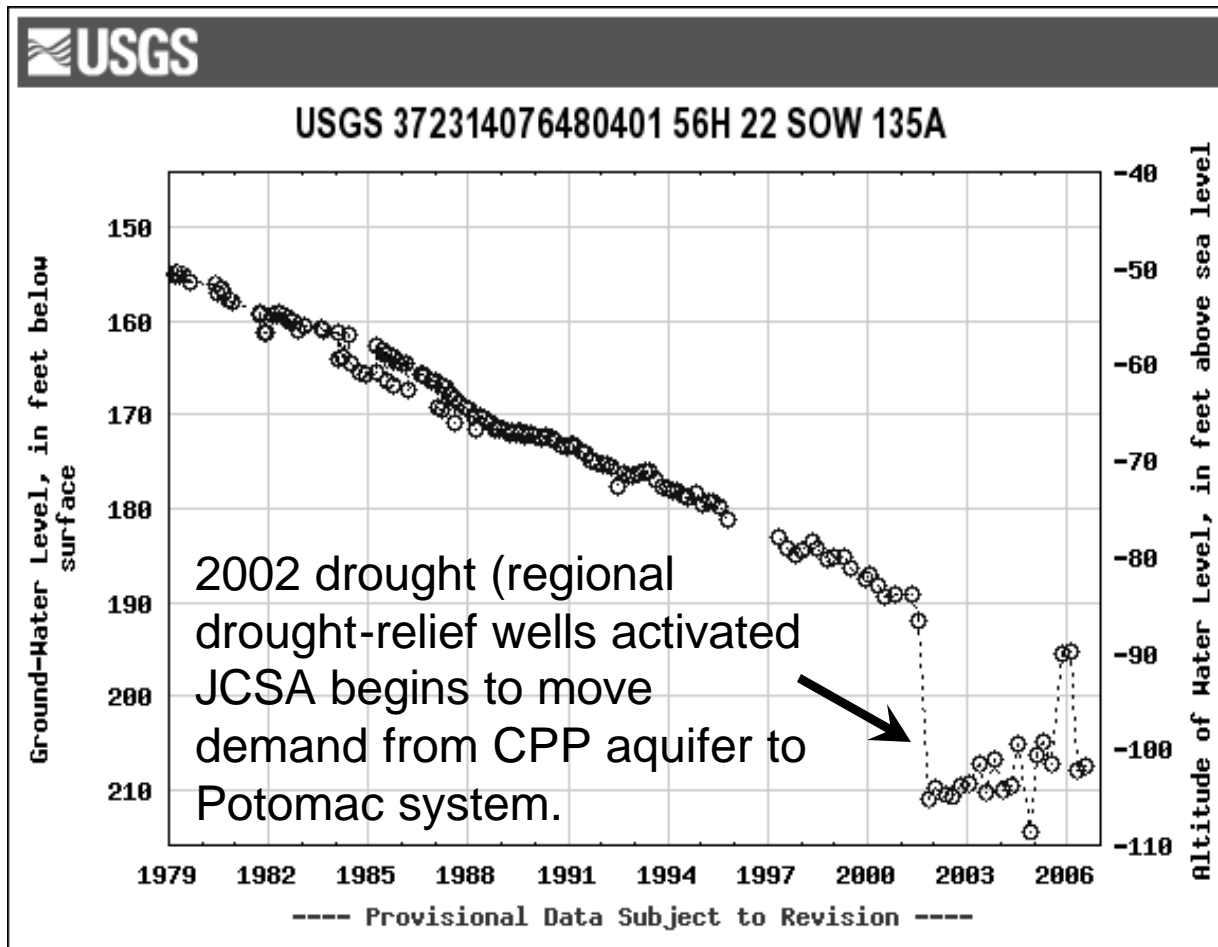


Barnes Road lower Potomac Aquifer



Top of the lower Potomac aquifer = 836 feet

Toano middle Potomac Aquifer



The Importance of Observations

- **Clarifies and/or Identifies Inconsistencies in Assumptions**
- **Provides model checks**
- **More specific locally**

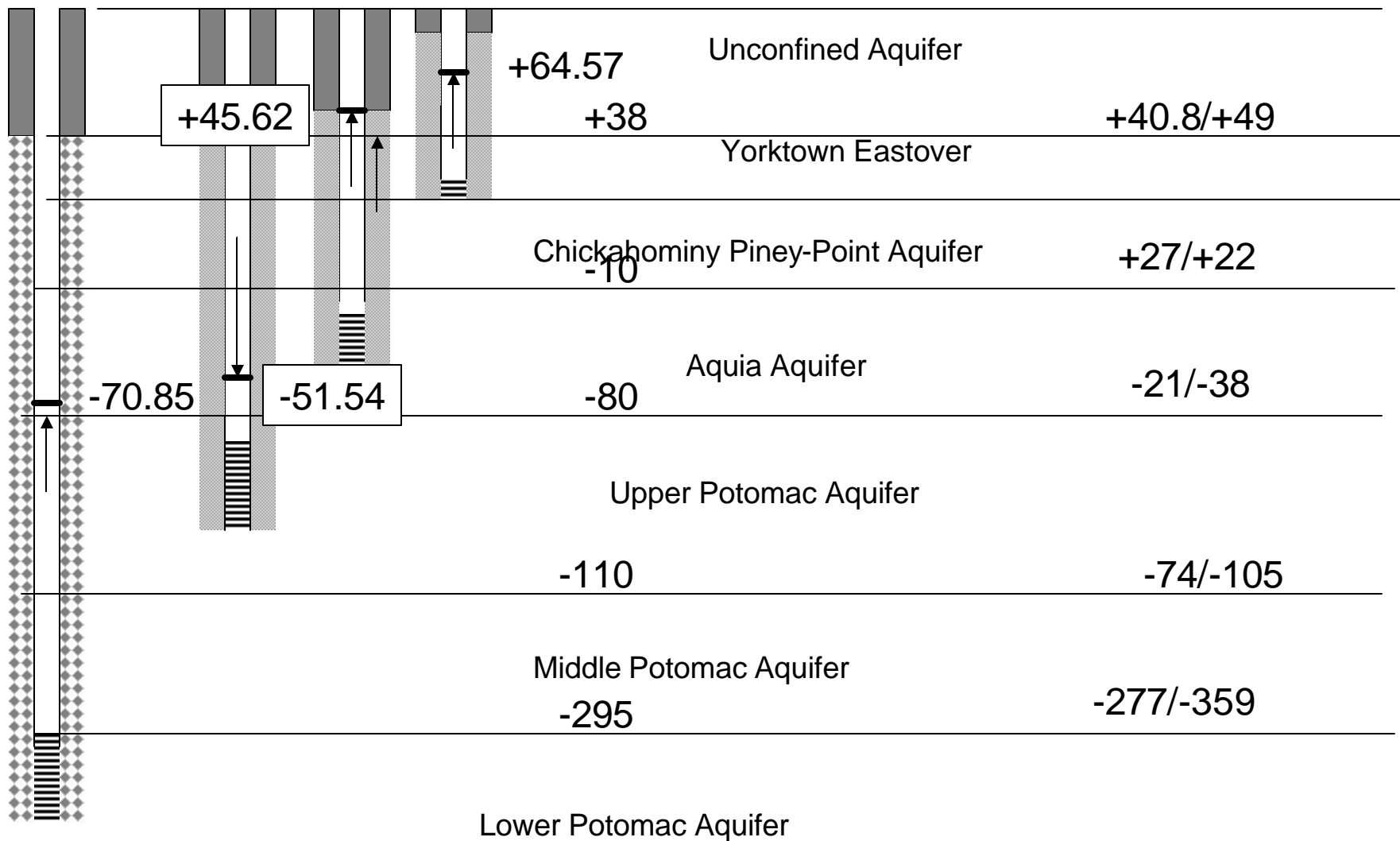
Cooperative Monitoring Network

See maps (page 7) in your book of illustrations.

Piezometer
Nest
Sebrell

Field measured water level
elevations (msl) and aquifer
tops (msl)

Simulated critical surface based
on simulated aquifer top and
prepumping heads from VCPM.



Not to scale, representational